United States
Department of
Agriculture

Forest Service

Pacific
Northwest
Region

**Siuslaw
National Forest**

Modeling The Effects of Forest Management on Salmonid Habitat

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March 1983

ABSTRACT

The Fish Habitat Index (FHI) is the product of habitat quantity (acres of salmonid habitat) and habitat quality (a numerical indicator of habitat condition). The index is a relative rating of the production potential of the fish habitat of an area. The index is first computed for natural conditions to reflect the inherent production potential of the fish habitat. It is then computed for managed (present and future) conditions to display the effects of forest management on the fish habitat. The FHI model provides land managers and resource professionals with an efficient and reliable means to assess relationships between management intensity, salmonid habitat, and watershed condition.

ACKNOWLEDGMENTS

We thank Hank Chrostowski and Tony Vander Heide for their administrative support, and George Bush, Steve Mellor, and John Berry for their vital roles in the developmental stage. We are indebted to Jan Smith for digitizing and data preparation, to Jim Grubb for computer program development and data processing assistance, and to Jere Christner, John Orsborn, and James Sedell for manuscript review.

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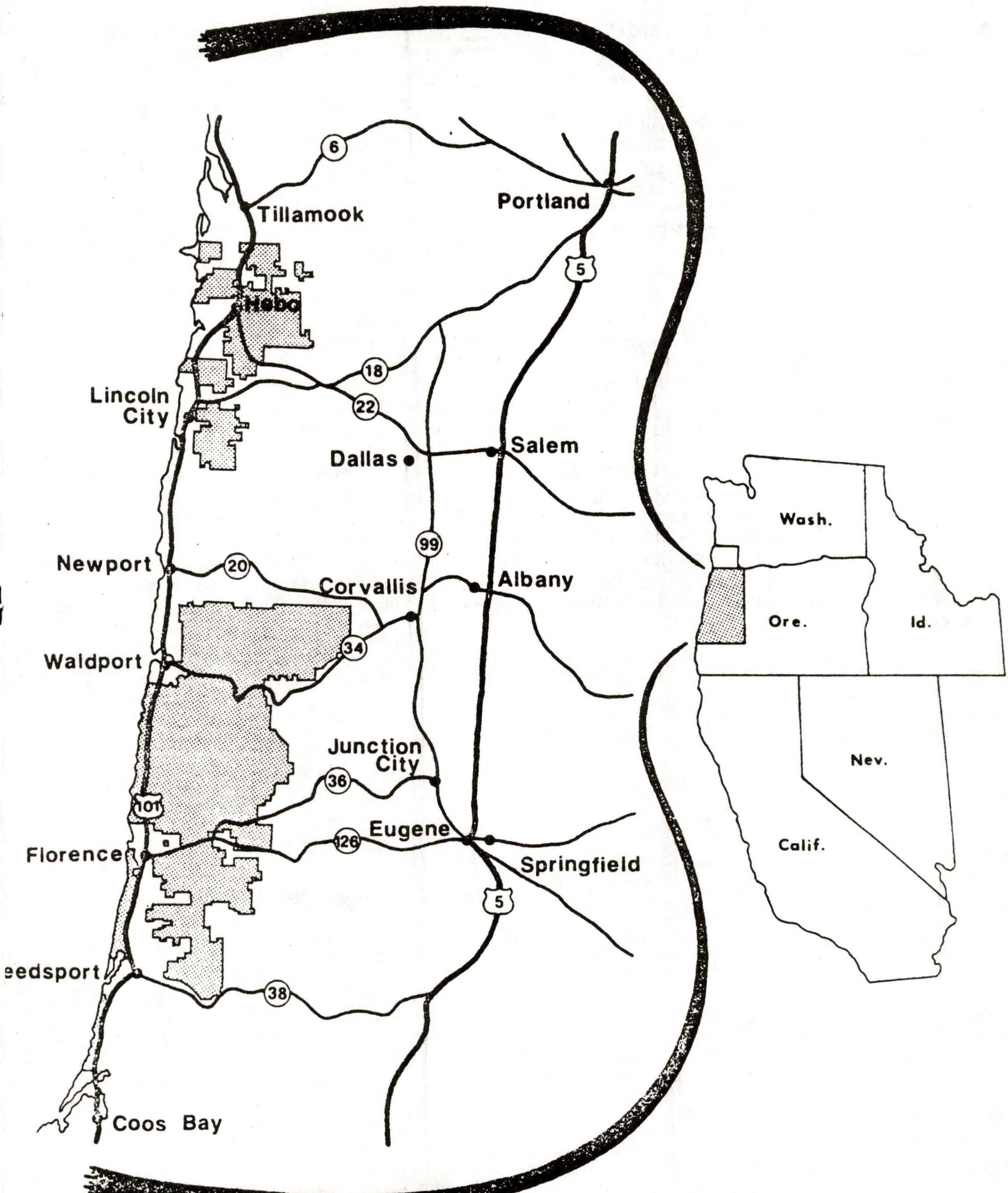
Vicinity Map

Siuslaw National Forest



STUDY SITE

The Siuslaw National Forest occupies 630,000 acres in the central Oregon Coast Range. The Forest is located almost entirely in the Coast Range section of the Pacific Border physiographic province. It has a maritime climate. Average annual precipitation is 100 inches, of which about 80 inches becomes runoff. Steep dissected slopes, cohesionless soils, and heavy precipitation contribute to active erosion processes. Sideslope steepness averages more than 60 percent, and ranges to 120 percent along many stream channels and headwalls. Density of stream channels range from averages of 7.7 miles per square mile to 11.6 miles per square mile in the most dissected landscapes. Lands considered high risk for accelerated landslide erosion following clearcutting or road construction compose 41 percent of the forest land available for timber harvest.

Of the 3,200 miles of perennial streams on the Forest, nearly 1,200 miles support anadromous salmonid fish. Five of the seven major coastal river systems that provide the largest numbers of steelhead and salmon to the estuarine and fresh-water sport fisheries of Oregon are partially included in the Siuslaw National Forest. The annual net economic value of the sport and commercial fisheries attributable to the Forest is about 22 million dollars. This value is calculated by updating the report completed by Kunkel and Janik (1976).

Two major natural vegetation zones occur on the Forest. The Sitka spruce zone occurs along the coast, and is only a few miles wide where it extends up river valleys (Franklin and Dyrness, 1973). The western hemlock zone covers the rest of the Forest. The major commercial conifers on the Forest are Douglas-fir, western hemlock, Sitka spruce, and western redcedar. The major commercial use of the Forest is timber production. An average of 380 million board feet of timber has been sold annually on the Forest during the past 10 years.

INTRODUCTION

In the past decade, increasing user demand and environmental awareness have multiplied the complexity of forest management. Concern for water quality and fisheries productivity has particularly increased in the Pacific Northwest. Increasing timber demands, declining fish runs, and State concern over waning salmonid habitat quality on National Forests are major issues. With the passage of the National Environmental Policy Act (1969) and the National Forest Management Act (1976), a more complex process of planning and decisionmaking on Federal lands has emerged. Techniques for quantifying the tradeoffs between management of various resources are needed to help make these complex multiple-use decisions more sound and objective.

The Fish Habitat Index (FHI) was developed to help meet this need on the Siuslaw National Forest. The index is a relative rating of the production potential of the fish habitat of an area. It is derived by multiplying habitat quantity (acres of salmonid habitat) by habitat quality (a numerical indicator of habitat condition). The purpose of the index is to display to land managers and resource professionals the tradeoffs between forest management and fish habitat.

Development of the index has been an interdisciplinary effort involving Forest and District personnel in fisheries, soils, and hydrology. A prototype FHI developed by Heller and Janik (1978) was initially used in the Forest Timber Resource Plan (1979) to include fish habitat in the decisionmaking. Since then, the index has been refined for the Siuslaw Forest Plan through a variety of data gathering and analytical activities.

This paper discusses the development and composition of the entire FHI model used in the Siuslaw Forest Plan. The following sections discuss: 1) basic concepts, 2) how the Forest land base was stratified into response units to increase analytical sensitivity, 3) how the FHI is computed for each response unit (eight sections), and 4) applications, limitations, and research needs.

BASIC CONCEPTS

The conceptual basis for the FHI model is that salmonid production potential is controlled by the quantity and quality of available habitat. The model requires three major assumptions: 1) a single set of parameters accurately reflects habitat requirements for all life stages of all salmonid species; 2) changes in habitat affect all species equally; and 3) multiplying habitat quantity by habitat quality reasonably reflects the salmonid production potential of the habitat.

Models are useful for Forest planning because they can assess complex resource tradeoffs objectively and mathematically. We believe the Siuslaw FHI model is especially useful because:

1. It addresses all the major physical processes affecting the quantity and quality of salmonid habitat.

2. It uses the available pertinent research and inventory data to simulate these physical processes.

3. It suggests practical areas for future research and monitoring.

4. It is flexible enough to accommodate new information.

5. It can be adapted to Regional, Forest, and basin levels of planning.

6. It expresses the relative production potential of salmonid habitat in a single number, thus promoting clear and simple analyses of alternatives.

The FHI is computed for three different time periods.

1. The natural FHI is computed to assess the inherent production potential of fish habitat without the influence of management. This represents a base line from which to assess the effects of management. It infers what fish habitat conditions were before comprehensive use of the Forest began in 1940.

2. The managed FHI for the present condition is computed to assess the production potential of fish habitat today, as affected by management activities since 1940. It represents a benchmark from which to forecast future trends.

3. The managed FHI for the future condition is computed to forecast relative changes in the production potential of fish habitat through future decades for each management alternative.

The natural FHI is computed differently than the managed present and future FHI's. Natural habitat quantity is the acres of available fish-bearing streams prior to management activities. Natural habitat quality is expressed by a dimensionless number between 0 and 10. Managed habitat quantity is reduced from natural levels by logjams and culverts blocking upstream habitat to migrating salmonids. It is replenished as these barriers are removed. Managed habitat quality is reduced from natural levels by accelerated sediment loads, increased water temperatures, reduced supplies of organic debris, and debris torrents. It is replenished as these impacts are mitigated. Figure 1 presents a flow chart showing the overall structure of the FHI model.

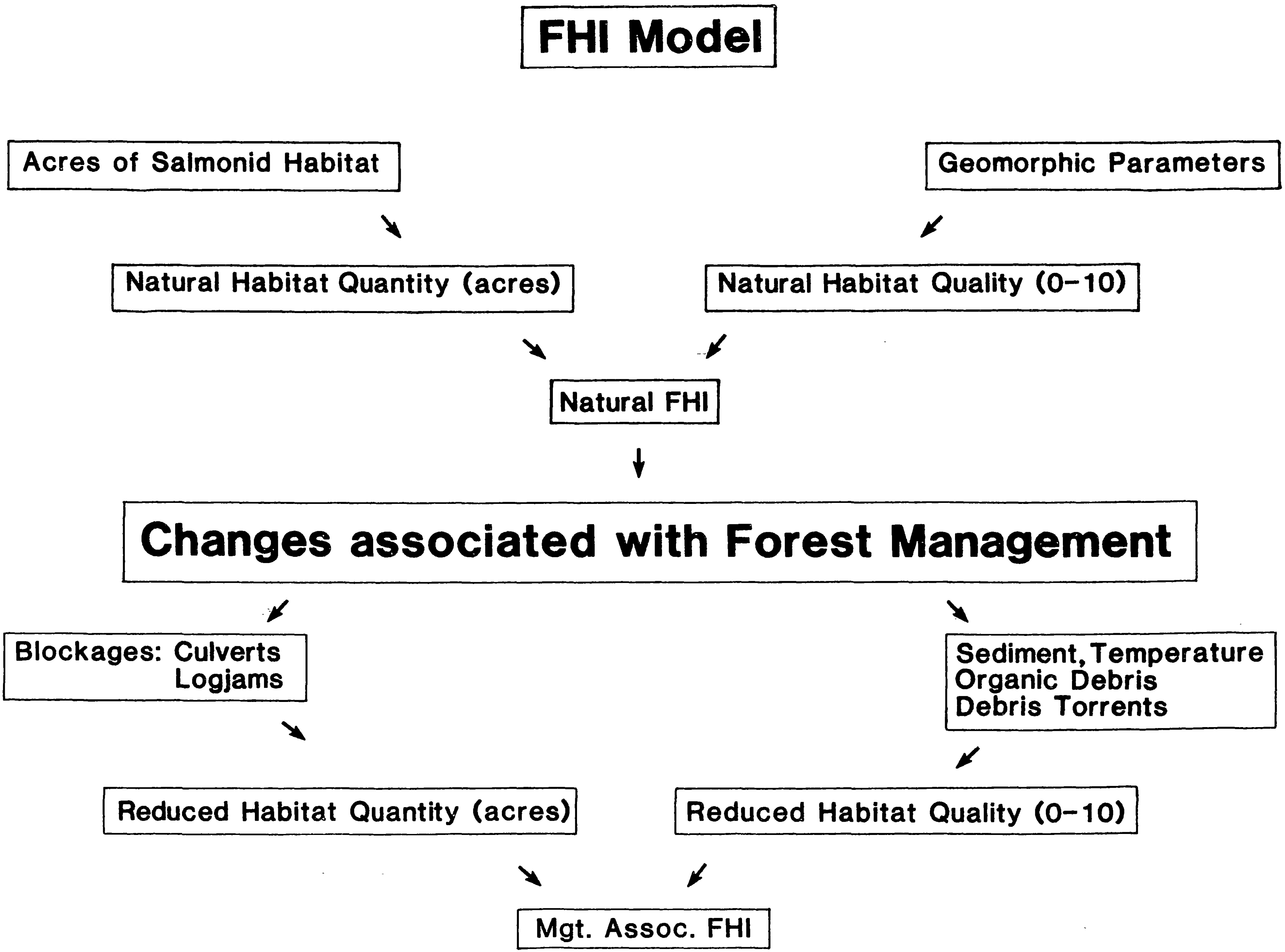


Figure 1. Overall structure of the FHI model

STRATIFYING THE LAND BASE

Because more than 240 fourth-order watersheds and six salmonid species exist on the Siuslaw National Forest, some generalization is needed to provide information that is meaningful both to decisionmakers and the public. Assessing individual watersheds or species is impractical. Variation in land and stream characteristics throughout the Forest, however, justifies some stratification of the land base to improve analytical sensitivity. The land systems inventory was used to delineate these strata.

The land systems inventory is a hierarchical land classification system. Its purpose is to delineate units of land having differences in land capability and suitability. The system integrates inventory needs for many resources for interdisciplinary decisionmaking. The delineated units reflect the action of climate on geology over time to produce an orderly array of landforms, soils, and vegetation. The units are useful as analysis, implementation, and monitoring areas.

Land systems inventory concepts have been presented by Wertz and Arnold (1972), Wendt et al. (1975), Region 1 of the USDA Forest Service (1976), and Platts (1980). Berry and Maxwell (1981) completed a land systems inventory for the Siuslaw National Forest. Units of land are described at nine hierarchical levels. Each succeeding level becomes more homogeneous in characteristics to satisfy increasingly specific information requirements. The landtype association level was used in applying the FHI model to Forest planning.

Fifteen landtype associations were defined on the Forest. These units average about 40,000 acres and reflect differences in patterns of lithology, geomorphic process, landforms, and vegetation. The 1:31,680 Soil Resource Inventory (SRI) was used as the basis for mapping. Two landtype associations do not contain significant acreages of commercial forest land, and thus were not included in the modeling base.

The SRI mosaic was color-coded to reflect the composite lithology, process, and landform features of each SRI landtype. Associated color patterns were used to draw preliminary landtype association boundaries. The mosaic was then taken to each District, where hydrologists, fisheries biologists, soil scientists, and foresters refined the mapping based on local knowledge of landform and vegetation. The result was a multiple-resource map reflecting major differences in land productivity, erosion hazard, water and sediment yield, and stream structure. FHI assessments were made independently for each landtype association.

NATURAL FHI

The objective of the natural FHI is to assess the inherent production potential of fish habitat without the influence of forest management. This represents a base line from which to assess the effects of management. It infers what fish habitat conditions were before comprehensive use of the Forest began in 1940.

The first two portions of this section explain how the data base was derived to allow estimates of natural habitat quality to be made. The third portion describes how habitat quantity and quality are derived and used to compute the FHI for each landtype association.

Determining Habitat Condition

In 1978 the Siuslaw National Forest began a stream survey program. The goal is to describe the physical habitat of streams, assess the productivity of resident and anadromous fisheries, and document the short and long-range impacts of forest management on the fisheries resource. As part of the program, a method to objectively assess the quality of salmonid habitats was developed. An intensive review of the literature and of existing approaches in habitat evaluation methods from Regions 4, 5, and 10 of the Forest Service and western districts of the Bureau of Land Management was made. From this review, Dave Heller and Steve Zemke (1979), fisheries biologists from the Mapleton Ranger District, developed a habitat condition rating method which was then standardized for the Forest (Parsons, 1980).

The method calculates a numerical index of fish habitat quality for each stream surveyed on the Forest. Criteria of streamflow, pool-riffle ratio, stream surface shading, pool quality, and riffle quality are used to calculate a Habitat Condition Score (HCS) for each reach. Reach scores are weighted by length and are used to develop an overall HCS for the stream. The full range of scores varies from 0 (very poor) to 10 (optimum). An adjustment factor may be applied to incorporate conditions not adequately reflected by the model criteria. Such conditions include: recent debris torrents, accelerated debris loads, erosion or deposition, or high salmonid populations. The HCS is useful as a means of comparison and for long-term resource monitoring and evaluation. Table 1 illustrates how the HCS was calculated for an actual stream. It displays the weights assigned to each component of the habitat being evaluated.

Table 1. Habitat Condition Score - Alder Creek, Hebo Ranger District.

Reach II - Alder Creek

Component (Data)	Rating	x	Weight	=	Score
I. Flow (0.5-1 cfs)	3		7		21
II. Pool:Riffle (7:3)	7		5		35
III. Shade (85-95%)	9		3		27
IV. Pool Quality (Depth 0.8-1.4 ft; Effective Cover 45-59%)	7		5		35
V. Riffle Quality					
A. Water Depth (0.2 ft)	4				
B. Bottom Comp. (Boulder-Rubble)	6				
C. Condition (Moderate Sediment Disposition)	5				
15/3 x	5		= 25		
Total			25		143
Unadjusted Score = 143/25	=				5.7
Adjustments:					
Moderate Nos. Salmonids	+				0.5
Adjusted Score =					6.2

Overall Score - Alder Creek

Reach	Score	x	Miles	=	Weight
I	6.0		0.5		3.0
II	6.2		1.7		10.54
III	4.0		0.6		2.4
			2.8		15.94/2.8 = 5.7

To generate a data base from which to predict natural habitat quality, HCS values for undisturbed watersheds were needed. The stream survey program had surveyed 38 such watersheds on the Forest by 1980. An HCS were derived for each watershed. Table 2 lists the stream name, location by landtype association and ranger district, and the stream's associated HCS. The next job was to develop a model that would predict these HCS (natural habitat quality) values with reasonable accuracy.

Table 2 Undisturbed Surveyed Watersheds by Location, Name and Habitat Condition Score

Landtype Association	Ranger District	Basin Ident. Number	Stream Name	Habitat Condition Score
Sedimentary Marine Hills	Mapleton	14B	Morris Creek	3.8
Cuestaform Lands	Waldport	22D	Stump Creek	6.4
	Mapleton	14I	Elma Creek	6.2
	Mapleton	15D	Upper North Fk. Indian Ck.	6.7
	Waldport	22E	Skinner Creek	3.8
	Waldport	23J	Tributary A	3.5
	Waldport	23K	Tributary B	3.4
	Waldport	23L	Winter Creek	1.9
	Waldport	23M	Bend Creek	4.0
	Waldport	23N	Helms Creek	6.0
	Alsea	28O	Alder Creek	4.1
Interior Fluvial Lands	Hebo	19D	East Fork Powder Ck.	4.5
	Hebo	19E	Middle Fork Powder Ck.	5.7
	Hebo	19F	South Fork Powder Ck.	7.1
	Hebo	19G	West Fork Niagara Ck.	6.5
	Hebo	19H	East Fork Niagara Ck.	6.0
	Hebo	19I	Middle Fork Niagara Ck.	5.0
	Hebo	57D	Limestone Creek	5.8
	Hebo	57K	Tony Creek	5.2
	Hebo	57V	Mina Creek	5.2
Coastal Fluvial Lands	Waldport	28E	Bear Creek	5.3
	Alsea	30C	Flynn Creek	5.5
Fine-Textured Fluvial Lands	Mapleton	19B	Brush Creek	4.5
	Mapleton	17O	Hoffman creek	5.3
Dense-Textured Fluvial Lands	Mapleton	5N	Perkins Creek	5.7
Igneous Headlands	Waldport	20A	Rock Creek	5.3
Igneous Marine Hills	Hebo	57D	Sanders Creek	4.6
Igneous Uplands	Waldport	14K	Boulder creek	5.7
	Waldport	30E	Cougar Creek	6.1
	Waldport	30M	Slide Creek	6.1
Intrusive Tablelands	Hebo	56D	Buck Creek	4.4
	Hebo	56E	Crazy Creek	6.9
	Hebo	56F	Three Rivers	4.3
	Hebo	57G	George Creek	7.5
	Mapleton	6E	Kentucky creek	7.8
	Mapleton	6J	Flow Creek	5.1
	Mapleton	6K	Steelie Creek	4.8
Igneous/Sedimentary Contact Lands	Mapleton	20G	Berry Creek	5.6

Selecting Geomorphic Parameters

Geomorphic parameters describe physical characteristics of drainage basins and stream networks. Since 1933, at least 49 publications have documented the use of geomorphic parameters to model annual runoff, base flow, peak flow, and sediment yield. In addition, the use of geomorphic parameters to assess fish habitat quality has a foundation in the literature. Thompson and Hunt (1930) stressed the importance of the entire watershed, not just the stream, to stream productivity. Slack (1955) showed that biological stream productivity is directly related to physical watershed characteristics controlling drainage pattern, flow rates, gravel sizes and shapes, channel gradients, and stream and slope stability. Ziemer (1971) developed an index system relating pink salmon escapement numbers to five geomorphic parameters in Alaska. Burton and Wesche (1974) related four geomorphic parameters to an index of standing crop of trout in small Wyoming streams and validated the model with standing crop estimates in other streams. Swanston et al. (1977) developed a regression formula with eight geomorphic parameters to estimate the productivity of salmon streams in 200 watersheds in southeast Alaska. Similarly, the FHI model uses geomorphic parameters to estimate the quality of fish habitat on the 38 undisturbed watersheds surveyed on the Siuslaw National Forest.

Marston (1978) identified 73 geomorphic parameters from the literature that had been used to model annual runoff, base flow, peak flow, and sediment yield. Analysis of physical processes suggested that 30 of these parameters might correlate with the quality of fish habitat. Four others were developed in the course of the analysis. The 34 geomorphic parameters tested and their derivation formulae are shown in Table 3.

The 34 geomorphic parameters were measured or derived for 240 fourth-order basins distributed randomly across the 13 landtype associations on the Forest (Calvin, 1981). Stream networks were delineated using contour bends (Marston, 1978) and were ordered using the system of Horton (1945) as modified by Strahler (1957). Figure 2 shows a sample basin and stream network.

The map of landtype associations was overlaid with a map of the 240 basins. Each basin was then identified with a landtype association. The values of geomorphic parameters could then be averaged for each landtype association.

Table 3 Geomorphic Parameters and Derivation Formulae

Symbol	Geomorphic Parameter	Derivation	Units	Reference
BA	Basin Area	Direct Measure	Sq.Mi.	Horton, 1945
BP	Basin Perimeter	Direct Measure	Mi	Smith, 1950
BL	Basin Length	Direct Measure	Mi	Potter, 1961
BR	Basin Relief	Direct Measure	Ft.	Schumm, 1956
TNS	Total Number of Streams	Direct Count	Enumerative	Horton, 1945
TSL	Total Length of Streams	Sum of Total Lengths	Mi	Horton, 1945
TSR	Total Relief of Streams	Sum of Relief of Streams by order	Ft.	*
RR	Relief Ratio	BR / (5280 x BL)		Schumm, 1956
B	Bifurcation Ratio	Antilog of slope of regression of stream order (U) vs. log of number of streams of order U. (NU)		Strahler, 1957
SRR	Stream Relief Ratio	Antilog of slope of regression of U vs. log of mean relief of streams of order of U $\frac{(RU)}{(NU)}$		Horton, 1945
SLR	Stream Length Ratio	Antilog of slope of regression of U vs. log of mean length of streams of order U $\frac{(LU)}{(NU)}$		Horton, 1945
SSR	Stream Slope Ratio	Antilog of slope of regression of U vs. log of mean slope of streams of order U $\frac{(RU)}{(LU)}$		Horton, 1945
SLB	Ratio of Stream Length Ratio to Bifurcation Ratio	SLR/B		Horton, 1945
SRB	Ratio of Stream Relief Ratio to Bifurcation Ratio	SRR/B		*
SSB	Ratio of Stream Slope Ratio to Bifurcation Ratio	SSR/B		*
DD	Drainage Density	TSL/BA	Mi/Sq.Mi.	Horton, 1945
WTF	Watershed Topography Factor	(B x SSR)/SLR		Anderson and Trobitz, 1949
CC	Compactness Coefficient	$BP / [2 \times (3.14 \times BA)^{1/2}]$		Rothacher et al., 1967
SF	Stream Frequency	TNS / BA	No/Sq.Mi.	Horton, 1945
RD	Relative Density	SF / DD^2		Melton, 1958
LOF	Length of Overland Flow	5280 / (2 x DD)	Ft.	Horton, 1945
C	Circularity	$(4 \times 3.14 \times BA) / BP^2$		Miller, 1953
CCM	Constant of Channel Maintenance	1 / DD	Sq.Mi./Mi	Schumm, 1956
FF1	Form Factor 1	BA / BL^2		Horton, 1932
L	Lemniscate	$BL^2 / (4 \times BA)$		Chorley et al., 1957
RER	Relative Relief	BR / (5280 x BP)		Strahler, 1964
RN	Ruggedness Number	(BR/5280) X DD		Melton, 1958
TE1	Transport Efficiency 1	B X TSL		Lustig, 1965
TE2	Transport Efficiency 2	TNS X SSR		Lustig, 1965
TSP	Texture Slope Product	DD X RR		Schumm, 1969
TR	Texture Ratio	TSR/BP		Strahler, 1957
MS	Mainstream Slope	Relief of fourth-order stream divided by length of fourth-order stream		Taylor and Schwarz, 1952
FF2	Form Factor 2	BL/BW		Horton, 1932
ARF	Basin Area Relief Factor	BA/BR		*

*Note: These parameters were developed by the authors to test

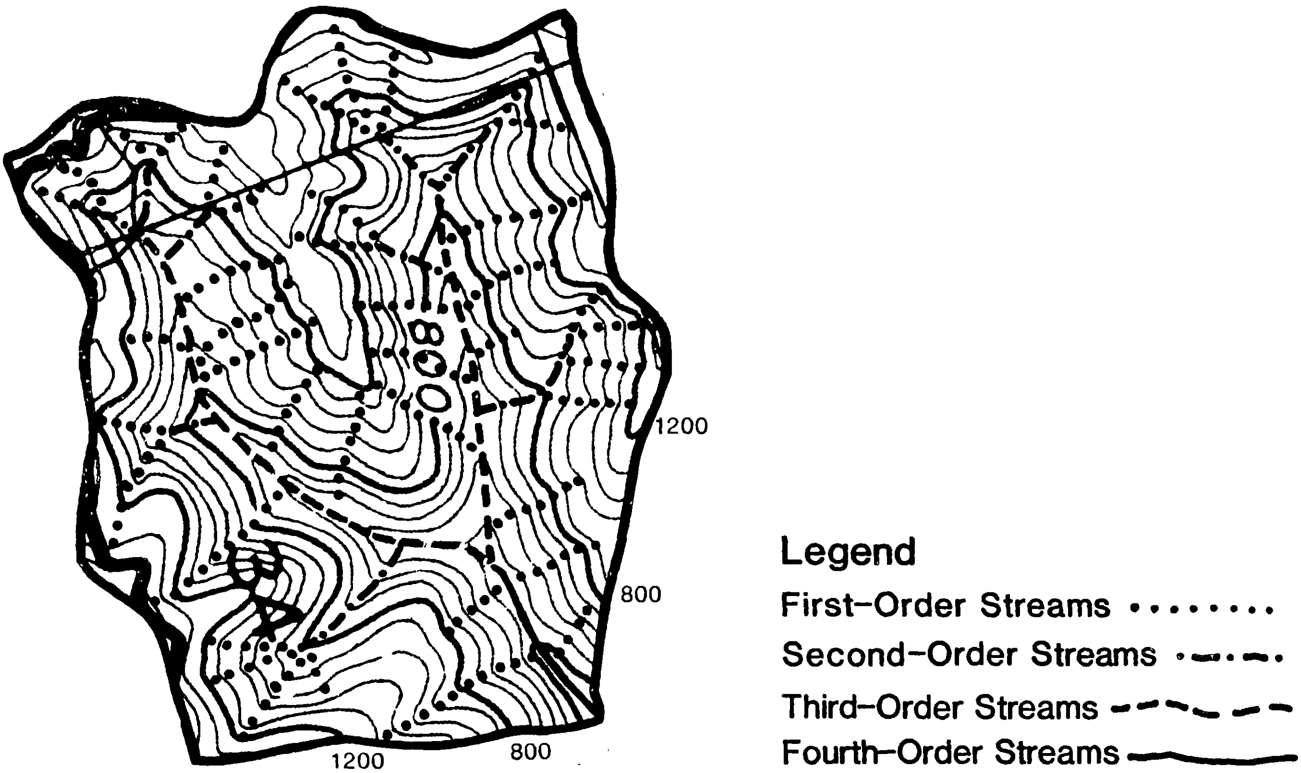


Figure 2. Delineation and ordering of drainage network.

Computing Natural FHI

The FHI is the product of habitat quantity and quality. It is important to understand how these values were derived.

Natural habitat quantity for each landtype association is the acres of salmonid habitat. The length of fish-bearing streams was measured on total resource inventory (TRI) compartment diazos using an HP-9874A sonic digitizer which operates from a Hewlett Packard 9845S desk-top computer. The length of streams blocked by natural falls and chutes was compiled from the stream survey reports and subtracted from the total stream mileage. Average bankful stream widths were calculated from stream survey data for each landtype association. Thus, the area of fish-bearing streams in each landtype association was calculated and expressed in acres.

Natural habitat quality for each landtype association is expressed by a dimensionless number between 0 and 10, predicted by a regression equation using four geomorphic parameters as the independent variables. The HCS was calculated for the 38 undisturbed watersheds and these scores were used as dependent variables. The 34 geomorphic parameters were independent variables used in a backward stepwise regression. The resulting equation could then be used to predict the natural quality number for all 240 basins on the Forest.

Since the undisturbed watersheds composed only 38 of the 240 basins for which geomorphic parameters were calculated, it was imperative that there be no differences in the geomorphic parameters between the disturbed and undisturbed basins. To investigate this possibility, the distribution of all variables of interest was examined. An ordered listing was made of the values of each variable, with the values for the undisturbed basins flagged for easy observation. If the values for the undisturbed watersheds were evenly or randomly distributed throughout the 240 basin values, 16 percent (representing four basins) of the top or bottom 25 values would be expected to be values of undisturbed basins. Analysis showed that the 240 basins could be assumed to have the same distributions as the undisturbed watersheds. Thus the analysis for development of a model for undisturbed basins could be run using all 240 basins.

To reduce the number of independent variables, all independent variables were examined for evidence of collinearity. Where a high correlation was found between two variables, one was deleted from further consideration. The variable deleted was the one which also showed high correlations with other independent variables, or seemed less likely from a physical basis to correlate with the HCS. The correlation coefficients between the HCS and the independent variables were examined next. Variables with a low correlation, indicating low predictive ability, were deleted. These two procedures reduced the number of independent variables from 34 to 10.

Finally, a step-wise regression analysis was run between the HCS and the remaining independent variables for the 38 undisturbed basins:

BP	=	Basin Perimeter	BR	=	Basin Relief
CC	=	Compactness	MS	=	Mainstream Slope
BA	=	Basin Area	LWR	=	Basin Length to Width Ratio
BL	=	Basin Length	DD	=	Drainage Density
RD	=	Relative Density	MS	=	Mainstream Slope
ARF	=	Basin Area Relief Factor			

The first four variables coming into the model are BP, BR, BA and CC in that order. All four regression coefficients are significantly greater than zero at $P = 0.05$. No other regression coefficients are significant. The resulting equation for calculating the natural quality number is:

$$\text{natural quality number} = 6.56 + 1.44(BP) + (0.00089)BR - 2.02(BA) - 5.62(CC)$$

The coefficient of determination is 0.60, meaning 60 percent of the variation in the FHI is explained by the four independent variables. The regression equation can be used to estimate the natural quality number for a given landtype association. One simply substitutes the mean values of basin perimeter, basin relief, basin area, and compactness coefficient for that landtype association into the equation.

The natural FHI is determined for each landtype association by multiplying the quantity, or acres of habitat, times the quality number as predicted by the regression equation.

MANAGED FHI: OVERVIEW

The objective of the managed FHI is to assess the production potential of fish habitat as affected by forest management. A present FHI is computed to evaluate fish habitat today, as affected by management since 1940. It represents a benchmark from which to forecast future trends. A future FHI is also computed for each Forest Plan alternative, to forecast relative changes in fish habitat through future decades. The future FHI is particularly useful to Forest planning decisions because it predicts the tradeoffs between forest management and anadromous fish habitat for any conceivable alternative.

The managed FHI is computed exactly the same way for both the present and the future. The model estimates reductions in both the quantity and the quality of fish habitat from natural levels. Habitat quantity is reduced by logjams and culverts that block upstream habitat from migrating salmonids. It is replenished as such barriers are removed. Habitat quality is reduced by exceeding certain thresholds of accelerated sediment loads, increased water temperatures, reduced supplies of organic debris, and debris torrents. It is replenished as these impacts are mitigated.

The following section explains how the model estimates the effects of forest management on habitat quantity. The next four sections explain how the model estimates effects on habitat quality, through impacts from sediment, temperature, organic debris, and debris torrents, respectively. Finally, the last section explains how the four individual quality indices are combined to yield an overall habitat quality index.

MANAGED HABITAT QUANTITY

The objective of this portion of the model is to estimate management-associated reductions in the amount of habitat available to anadromous salmonids in each landtype association. Habitat quantity is reduced by migration barriers in the form of improperly installed culverts and logjams created by management-associated landslides.

Culverts

Culverts blocking fish migration were identified through the Forest's stream survey program. The length of fish-bearing streams blocked by culverts was measured on TRI compartment diazos using a sonic digitizer. Average bankful stream widths were calculated from stream survey data for each landtype association. The acres of fishbearing streams blocked by culverts were then calculated and subtracted from the total habitat quantity for each landtype association.

Logjams

Logjams blocking fish migration (other than natural logjams) are a result of management-associated landslides. Landslide frequency depends on the amount of energy applied to the slopes versus the strength of the slopes. Very steep slopes receiving abundant rainfall are marginally stable and depend greatly on vegetation root strength to resist failure. The natural process of landsliding is accelerated when logging reduces root strength, or road construction overloads, undercuts, or concentrates water on slide-prone sites. The revised Soil

Resource Inventory (SRI) was used to group soil mapping units into high- and low-risk categories for landslide acceleration based on slope morphology and inventoried landslide activity on managed lands. Frequency and volume of sediment for natural and management-associated landslides on the Forest have been established for most SRI mapping units by Swanson and Swanson (1977), Dipert (1978), Ketcheson and Froelich (1978), Gresswell et al. (1979), and Barnett (1980).

Using data from the above studies, Bush (1982) developed a model that estimates the frequency and sediment volume of landslides caused by clearcutting and roadbuilding. The basic rate varies for clearcutting depending on the risk category of each soil mapping unit, and for roads depending on the construction category of the road. The landslide rate associated with clearcutting can be reduced by retaining the vegetation on and around slide-prone sites.

For clearcut-associated landslides, Bush consolidated the landslide frequency and sediment data for individual soil mapping units in each risk category. From these data, he computed average landslide frequencies and sediment volumes for completely clearcut areas in each risk category. He generated data on the mitigating effects of vegetation leave areas using opinion surveys of experienced field personnel (McNutt, 1975). The computed frequency rates are:

Landslide Frequency (no./acre clearcut)

Risk Category	Completely Clearcut	2.5-Acre Leave Areas	5.0-Acre Leave Areas
High	.0412	.0247	.0165
Low	.00965	.00579	.00386

For road-associated landslides, Bush generated landslide frequency and sediment data for three construction categories of roads: 1) "old roads" built before 1975, when improved construction and maintenance techniques were introduced; 2) "new roads" built since 1975 using the improved techniques and since stabilized; and 3) "future roads" to be built after 1982. The future roads produce high landslide rates immediately following construction, and then decline to the stable "new road" rate. The computed frequency rates are:

Construction Category	Landslide Frequency (no./road acre/year)
Old	.0167
New	.00321
Future	.00642

To compute the total number of management-associated landslides occurring in each landtype association for any time period, one simply enters the acres of each type of clearcut per risk category and the miles of road per construction category into the model. The model computes the totals for each category and then sums these totals. Inventories at Mapleton indicate that an average of 12.2 debris torrents (those that travel more than 800 feet) are produced per 100 land-slides, and that 8.4 of these major debris torrents result in logjam migration barriers.

Inventoried landslides on the Forest are generally caused by floods with recurrence intervals of 2-10 years. Such events have a 70-100 percent chance of occurring once in any 10-year analysis period. The model assumes floods of similar magnitude occurring once per decade in the future. It does not account for extreme events, e.g. 50- or 100-year floods, whose impact would be far more catastrophic.

To locate logjams in the stream network, a simulation model was developed by Dr. Lyle Calvin of the Oregon State University Department of Statistics. Calvin states (1981):

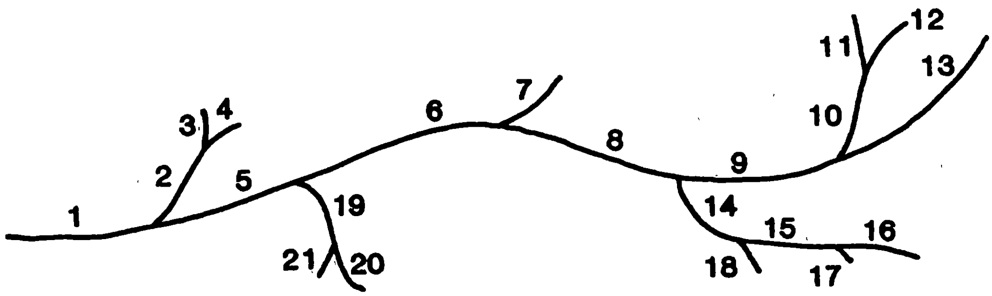
> "Although the occurrence and location of specific logjams cannot be predicted, it can be assumed that one will occur in a given period of time in a given portion of stream, with a probability that will vary by landtype association. Logjams are expected to occur randomly, both in space and time, and their lifetime is expected to follow a specific distribution. These factors were brought together to develop a model which could be used to simulate the occurrence of logjams over any desired number of years. The basic development of the model for a given landtype association is as follows:
>
> let p = probability that a logjam occurs in a given mile of stream within one year.
>
> x = length of stream (miles)
>
> y_i = length of stream (miles) blocked by the ith logjam
>
> The probability that k logjams will occur in x miles of streams in a year is given by:
>
> $P(k) = \binom{x}{k} p^k q^{x-k}$ where $q = 1-p$
>
> "If x is large (say above 25) and px or qx not too small (say, not below 5), then the normal approximation can be used to approximate the binomial distribution of k by setting $u=px$ and $\sigma^2=pq/x$. From this equation is developed the distribution of the number of logjams over years.

"The probability that a logjam will occur in a given mile of stream varies by landtype association and must be estimated from empirical data or estimated by some other reliable method. It is assumed that soil scientists and foresters can provide a reasonable estimate of this probability. The expected longevity of a logjam to block fish passage is also needed. This factor must come from historical records or from the expert judgment of experienced biologists."

From opinion surveys of experienced field personnel, it was estimated that logjams remain migration barriers for a minimum of five years and a maximum of 20 years. Therefore, in the simulation model, logjams that had been in place for five years or longer were available to be randomly selected out. This was done to simulate the process of logjams naturally breaking up during runoff events.

Given the above information, Calvin advises:

"For each stream, code each stream segment by counting sequentially along the left-most available segment. For example:



"For each stream segment, the length of the segment is recorded, and whether the segment has an end not connected to another segment. For example, Segments 3, 4, and 7 have such ends, but Segments 1, 2, 5, and 6 do not. The information on segment end is used to determine quickly, by computer, which segments are blocked by logjams. Thus, simulation over a number of years is carried out by:

1. Selecting k for each year with probability proportional of P(k).

2. Selecting the location of each logjam with equal probability for each mile of stream.

3. Deleting logjams after t years with probability proportional to the relative life of logjams.

"To meet the objective of simulating logjams in an entire landtype association, the results on individual streams must be expanded to the full block. This involves a replication of the sample streams to make the total number of river miles of sample streams equal to the total river mileage in the landtype association. This is done by randomly sampling enough sample streams, or portions of them, to add to the original sample, to obtain a sample mileage equal to the total mileage of the landtype association.

"For example, assume four sample streams have river mileages of:

Stream No. 1 = 4.77 miles
Stream No. 2 = 13.08 miles
Stream No. 3 = 5.33 miles
Stream No. 4 = 3.12 miles

for a total of 26.32 miles. By adding Streams No. 2 and 3 a second time (a sample of streams No. 1, 2, 2, 3, 3, 4) a sample total of 44.74 miles is obtained, which is nearly equal to 44.7, the number of river miles in the land-type association. Simulation is then carried out on the six streams, simulating the entire stream mileage of the landtype association."

The simulation program output displays, for each year (see example, Appendix I), a record that includes the following: 1) number of logjams occurring during the year; 2) number of logjams naturally breaking up during the year; 3) number of logjams remaining at the end of the year; 4) the number of stream miles blocked by all logjams; 5) the number of stream miles remaining blocked in that given year if the worst logjam were removed; 6) the number of miles remaining blocked in that year if the second worst logjam were removed; and 7) the number of miles blocked by the worst logjam in that given landtype association.

With this model predicting the frequency and location of logjams, it is possible to determine the effects of forest management on habitat quantity and also look at the benefits of removing logjams. Mitigation measures can thus be simulated and economic analyses can be performed, in addition to quantifying the amount of habitat blocked to fish access.

Assumptions

Several basic assumptions are used for this portion of the FHI model. The term "assumptions" is used because this extra data were either based on limited studies or generated by opinion surveys of experienced field personnel using the approach of McNutt (1975). Appendix II explains in detail the survey procedures used. The major assumptions are:

1. Accelerated landslides result only from floods with recurrence intervals of two to 10 years.

2. Logjam migration barriers result from 8.4 percent of management-associated landslides.

3. Logjams remain migration barriers for 5-20 years. (Determined randomly for each barrier.)

4. Protecting identified slide-prone sites with 2.5-acre vegetation leave areas reduces land-slide rates from logging by only 52 percent. Using 5.0-acre leave areas reduces rates by only 62 percent. These inefficiencies are caused by incremental reductions in leave area effectiveness due to problems of site identification, layout, felling and yarding, slash burning, and hazards of windthrow.

5. Modified roadbuilding practices since 1974 have reduced landslide rates from roads by 70 percent. Improved road design, construction, and maintenance techniques have reduced the incidence of sidecast failures.

MANAGED HABITAT QUALITY: SEDIMENT

The objective of this portion of the model is to estimate impacts of management-associated sediment loads on fish habitat quality in each landtype association. The model calculates natural sediment yields and management-associated sediment yields from both landslides and surface erosion. Finally, the ratio of accelerated to natural sediment loads is used to generate a "sediment index" (SI).

Natural Sediment

Natural sediment yield for each landtype association is estimated using geomorphic parameters. Marston (1978) found nine studies that had used 20 geomorphic parameters to estimate sediment yields in the United States since 1949. Maxwell and Marston (1980) correlated mean annual sediment yield with geomorphic parameters for undisturbed watersheds in western Oregon. Maxwell (1983) improved on this relationship, correlating natural sediment yield with four geomorphic parameters (drainage intensity, drainage ratio, stream relief intensity, and stream relief ratio) for six research watersheds in western Oregon. The coefficient of determination for the highly significant relationship is 0.97. Natural sediment yield is estimated using the following equation:

$$Y = \frac{398 - 0.000973(2000-X)^{1.7}}{640}$$

where Y = sediment yield (cubic yards per acre per year) and X = erosion factor (product of the four geomorphic parameters). Each geomorphic parameter is measured for each fourth-order basin. The average value of each is computed for the landtype association. The natural sediment yield for the landtype association is calculated using these average values of the geomorphic parameters. A detailed discussion of the geomorphic parameters and the estimating technique is given by Maxwell (1983). The average natural sediment yields for the 13 major landtype associations used in the modeling base are:

Landtype Association	Sediment Yield (cu.yd./acre/year)
Igneous-sedimentary contact lands	.173
Igneous marine hills	.178
Intrusive tablelands	.197
Volcanic uplands	.249
Interior fluvial lands	.284
Sedimentary marine hills	.285
Cuestaform lands	.315
Igneous uplands	.348
Coastal fluvial lands	.407
Transitional fluvial lands	.442
Fine textured fluvial lands	.466
Dense textured fluvial lands	.604
Igneous headlands	.611

Management-Associated Landslide Sediment

The "MANAGED HABITAT QUANTITY" section (page 13) explained how Bush's (1982) model estimates the frequency and sediment volume of landslides caused by clearcutting and road building. For clearcut-associated landslides, the sediment rates are:

---Landslide Sediment Volumes---
(cu.yd./acre clearcut/yr.)

Risk Category	Completely Clearcut	2.5-Acre Leave Areas	5.0-Acre Leave Areas
High	11.9	7.14	4.76
Low	2.80	1.68	1.12

For road-associated landslides, the sediment rates are:

Construction Category	Landslide Sediment Volumes (cu.yd./road acre/yr)
Old	10.0
New	2.76
Future	5.52

To compute the total volume of management-associated landslide sediment produced in each landtype association for any time period, one simply enters the acres of each type of clearcut per risk category and the miles of road per construction category into the model. The model computes sediment yields for each clearcut/risk category and for each road construction category. It then sums these totals to derive the "grand total" management-associated landslide sediment yield for the landtype association.

Management-Associated Ravel Sediment

Slash left on completed clearcuts on the Siuslaw National Forest is usually broadcast burned to reduce fire hazards and brush competition and to prepare sites for tree planting. If the slash burn is hot enough to consume the organic matter at the soil surface, dry-ravel erosion will result on steep slopes. Bennett (1981) determined rates of such dry-ravel erosion to be 119 cubic yards per acre on slopes steeper than 60 percent, and 15 cubic yards per acre on 22-60 percent slopes. She also computed the sediment-contributing slope distance from the stream at 17.8 feet on the steeper slopes and 3.58 feet on the moderate slopes.

Using Bennett's data, Bush (1982) developed a model that estimates dry-ravel sediment production from steep (steeper than 60%) and moderate (22-60%) stream-adjacent slopes. The amount of sediment produced depends on the extent of contributing sediment-source area and the percent of this source area that is intensely burned.

Bush computed dry-ravel sediment yield independently for three categories of stream-adjacent slopes: 1) high-risk intermittent streams; 2) low-risk intermittent streams; and 3) all perennial streams. Perennial streams were distinguished because they are commonly not burned or burned on one slope only and have more gentle slopes. For each stream category, the extent of contributing sediment-source area depends on the drainage density of the streams and the steepness of the stream-adjacent slopes. The percent of this source area that is intensely burned depends on how much of the area is already in vegetation leave areas to prevent landslides, and on how much of the remaining area is burned in summer when fuels and slopes are relatively dry. For any combination of slope steepness and stream category, Bush computed dry-ravel sediment yield using the following equation:

$$Y = \frac{(V \times CW \times S \times DD)(I \times O)}{43{,}560 \text{ sq.ft./acre}}$$

where Y = sediment yield (cu.yd./acre), V = erosion rate for slope category (cu.yd./acre, from Benett, above), CW = contributing slope width (feet, from Benett, 1981), S = percent of slopes in stream category in a given slope class, DD = drainage density of streams in given stream category (feet/acre), I = percent of contributing area burned intensely, and O = percent of stream adjacent slopes not protected by vegetation leave areas. Following are basic data and sediment yield rates (cubic yards per acre clearcut) for the four stream categories:

Parameter	High-Risk Intermittent	Low-Risk Intermittent	Perennial
	---------Stream Category--------		
Drainage Density (mi./sq.mi.)	67.0	44.5	23.9
Percent Burned Intensely	40	40	10
Sediment Yield (cu.yd./acre/yr.)	1.56	1.18	0.176

To compute the total volume of management-associated ravel sediment produced in each landtype association for any time period, one simply enters the acres clearcut per stream category into the model. The model computes the totals for each category and then sums these totals.

The model underestimates management-associated sediment yields because two sediment processes are not addressed. One is surface erosion from roads. The other is accelerated channel erosion caused by disturbance of streambank soil and vegetation. For example, these erosion sources may account for up to 20 percent of total annual accelerated sediment. However, no studies have been conducted in the central Oregon Coast Range on this source of sediment yield.

The Sediment Index

The model sums the management-associated (landslide and ravel) sediment totals for each landtype association. It then must account for the facts that (1) only the bedload portion of the delivered sediment affects habitat quality for a significant length of time, and (2) it takes several years for all the delivered bedload sediment to flush from the system. Based on data from clearcut and burned Needle Branch in the Alsea Study (Harris, 1977), the model computes sediment loads to the fish habitat as a function of time since delivery as follows:

Years Since Logging	Percent of Sediment Left in Channel
1	60
2	36
3	18
4	6

The model uses the adjusted sediment load totals to compute a "sediment index" for each landtype association. The equation used is:

$$SI = \frac{Sn + Sm + Sl}{Su - Sl}$$

where SI = sediment index, Sn = natural sediment load, Sm = management-associated sediment load, Sl = "lower threshold" sediment load, and Su = "upper threshold" sediment load. The SI is zero until total (natural plus managed) sediment loads exceed the lower threshold. The index is 1.00 when total sediment loads reach the upper threshold.

The rationale behind the lower threshold is that native salmonids are accustomed to the wide year-to-year variations in natural sediment loads characteristic of the Oregon coast. The model assumes that a 25 percent increase above average natural levels is required before measurable reductions in habitat quality begin. These increases are averages over entire landtype associations. However, some drainages within a landtype association, due to cutting patterns, may experience more than a 25 percent increase above the natural sediment level for that drainage.

The rationale behind the upper threshold is that sediment alone can destroy the quality of salmonid habitat if loads become great enough. The model assumes that if sediment loads are increased 330 percent above average natural levels, then habitat quality will be reduced to zero even if no impacts occur from temperature, organic debris, or debris torrents.

Assumptions

Several assumptions are used for this portion of the model. These extra data were either based on limited studies or generated by opinion surveys (see Appendix II). The major assumptions are:

1. Introduced sediment flushes through a fourth-order stream network in five years.

2. Streamside leave strips reduce dry ravel sediment loading from slash burning by only 57 percent. Uphill directional felling reduces it by only 40 percent. These inefficiencies are caused by incremental reductions in leave strip effectiveness due to problems of site identification, layout, and felling and yarding.

3. Sediment loading begins to affect habitat quality only when it exceeds average natural levels for the landtype association by 25 percent.

4. Sediment loading alone will reduce habitat quality to zero when it exceeds average natural levels for the landtype association by 330 percent.

MANAGED HABITAT QUALITY: TEMPERATURE

The objective of this portion of the model is to estimate impacts of management-associated increases in water temperature on fish habitat quality in each landtype association. Brown (1972) showed that temperature increases are a function of the stream area exposed to sunlight, the solar angle, and the streamflow. The model first calculates stream exposure for the fish streams and their perennial tributaries. It then combines the stream exposure with solar angle and base flow values to derive a "heating factor". Finally, the heating factor is used to generate a "temperature index."

Stream Exposure

The natural forest vegetation in the riparian area (a 100-foot strip on each side of all perennial fish streams and tributary streams) keeps summer water temperatures in undisturbed coastal streams below 60°F in most years. Temperatures are increased as this vegetation is removed.

The model calculates stream exposure as a function of two disturbances. First is the percentage of riparian acres harvested. Streams alongside these acres are fully exposed. The second disturbance is the percentage of riparian acres where the forest immediately upslope is harvested. In this case, the riparian area acts as a leave strip. Streams alongside these acres are partially exposed, due to inefficiencies in implementing the leave strips correctly (see "Assumptions" below). The model sums the two values of stream exposure for the landtype association.

The model must account for the fact that clearcut acres continue to contribute to stream exposure for several years, until regrowth and canopy closure restore vegetal shade to natural levels. Mean stream widths were calculated for fish streams and their perennial tributaries, from stream survey data. Widths average 19.3 feet for fish streams and 6.9 feet for perennial tributaries. The mean solar angle for the Forest is 67^{o}. Personal communications with the Forest silviculturist (Turpin, 1982) led us to establish Table 5 below. A linear relationship between height and age of red alder was established from a height-age curve displayed by Williamson (1968). The equation is: height = 2.9 x age - 12.6. However, it is not until the sixth year that alder out-competes the brush. Therefore, years 1-5 reflect estimates of streamside brush growth on the Forest. However, it should be understood that red alder needs exposed mineral soil to begin regeneration. If stream adjacent areas aren't burned or disturbed, alder regeneration rate is likely much slower.

Table 5 Percent of stream naturally shaded that remains exposed

Year Since Cut	Height of Cover in Feet	% Fish Stream Exposed	% Perennial Tributary Exposed
1	2	.96	.88
2	3	.93	.81
3	4	.91	.75
4	5	.89	.69
5	6	.87	.63
6	6	.87	.63
7	7.5	.84	.54
8	10.3	.77	.36
9	13.2	.71	.18
10	16.1	.65	.01
11	18.9	.58	
12	21.8	.52	
13	24.7	.46	
14	27.5	.39	
15	30.4	.33	
16	33.3	.27	
17	36.1	.21	
18	39.0	.14	
19	41.9	.08	
20	44.7	.02	

The model shows that clearcut riparian and upslope acres continue to contribute to stream heating for up to 20 years after harvesting. The total stream exposure value for the landtype association in any given year is therefore a function of stream exposure in preceding years as well as the current year.

The model must also account for the fact that exposing perennial tributaries will heat even fully-protected fish habitat downstream. This influence is modeled as a function of relative base flows. The ratio of the sum of basin areas of all perennial tributaries to the total area for each fourth-order basin is calculated. These ratios are averaged for the landtype association. The resulting "basin area ratio" is used to express the percentage of the base flow in the fish stream that is contributed by its perennial tributaries. This ratio is used to show the effect of perennial tributaries on "effective stream exposure" in the fish streams. For example, if the basin area ratio were 0.5, the model would show that fully exposing all perennial tributaries would heat the fish streams as much as fully exposing half of the fish streams themselves. Of course, such drastic disturbances are never even approached over an entire landtype association.

Stream exposure is computed by the following equation, which is simplified here for discussion:

$$SE = \frac{r(B+1) + (1-E)(R-r)(u/U)(B+1)}{R}$$

where SE = stream exposure, R = total acres of riparian area, r = acres of riparian area harvested, U = total upslope acres, u = upslope acres harvested, B = basin area ratio, and E = leave strip effectiveness. The left term reflects the full stream exposure caused by harvesting riparian acres along fish streams and their perennial tributaries. The right term reflects the partial stream exposure caused by harvesting immediately upslope from the riparian area. In the model, the values of r and u are computed to account for regrowth (Table 5). SE is a dimensionless number between zero and one. Its value is zero for undisturbed forest and one when all fish streams are totally exposed.

The Heating Factor

Needle Branch is the only watershed in the Coast Range where complete watershed clearcutting has been related to stream temperatures and habitat quality (Moring and Lantz, 1975; Harris, 1977). The model uses Needle Branch as a "common denominator" to show how differences in solar angle and base flow between landtype associations modifies the effect of stream exposure on water temperature. The model reflects these influences by modifying the basic stream exposure value into a "heating factor". The equation used is based on Brown (1972):

$$HF = \frac{SE(SAF)}{BF}$$

where HF = heating factor, SE = stream exposure, SAF = solar angle factor, and BF = base flow factor. HF is a dimensionless number between zero and one. Like SE, its value is zero for undistrubed forest and one when all fish streams are totally exposed.

The solar angle factor is the median solar angle of the landtype association divided by the solar angle of Needle Branch. It shows that temperature increases are greater per unit of stream exposure as one goes south and the sun is more directly overhead. Analysis showed that solar angle differences between the north and south ends of the Forest are not significant. Therefore, the solar angle factor did not influence the modeling.

The base flow factor is the mean base flow of the landtype association divided by the base flow of Needle Branch. It shows that temperature increases are greater per unit of stream exposure in watersheds having lower base flows where there is less water to heat in the summer. Base flow is estimated using geomorphic parameters. Maxwell and Marston (1980) correlated base flow with four gemorphic parameters for six research watersheds in western Oregon. The coefficient of determination for the highly significant relationship is 0.84. Base flow is estimated using the following equation:

$$Y = 1.08 + .0139 \times \frac{B(SRR)}{RR(CC)}$$

where Y = base flow (cfs per square mile), B = bifurcation ratio, SRR = stream relief ratio, RR = relief ratio, and CC = compactness coefficient. Each geomorphic parameter is measured for each fourth-order basin. The average value of each is computed for the landtype association. The base flow value for the landtype association is calculated using these average values of the geomorpic parameters. A detailed discussion of the gemorphic parameters and the estimating technique is given by Maxwell and Marston (1980).

The Temperature Index

The model uses the heating factor to compute a "temperature index" for each landtype association. The equation used is:

$$TI = \frac{HF - Hl}{Hu - Hl}$$

where TI = temperature index, Hl = "lower threshold" heating factor, and Hu = "upper threshold" heating factor. The temperature index is zero until the heating factor exceeds the lower threshold. The index is 1.00 when the heating factor reaches the upper threshold.

The rationale behind the lower threshold is that native salmonids have adapted to some fluctuation in maximum stream temperature. The model assumes that a heating factor of 0.15 (corresponding to an effective stream exposure of 15%) is required before measurable reductions in habitat quality begin.

The rationale behind the upper threshold is that high temperatures alone can destroy the quality of salmonid habitat if enough streams are exposed. The model assumes that if the heating factor is increased to 0.73 (corresponding to an effective stream exposure of 73%), then habitat quality will be reduced to zero even if no impacts occur from sediment, organic debris, or debris torrents.

Assumptions

Several assumptions are used for this portion of the model. These extra data were either based on limited studies or generated by opinion surveys (see Appendix II). The major assumptions are:

1. Regrowth and canopy closure restore shading on exposed streams to natural levels within 20 years.

2. Streamside leave strips provide only 43 percent of natural shade. This inefficiency is caused by incremental reductions in leave strip effectiveness due to problems of site identification, layout, felling and yarding, slash burning, and windthrow.

3. Water temperatures begin to affect habitat quality only when effective stream exposure for the landtype association reaches 15 percent.

4. Water temperatures alone will reduce habitat quality to zero when effective stream exposure for the landtype association reaches 73 percent.

MANAGED HABITAT QUALITY: ORGANIC DEBRIS

The objective of this portion of the model is to estimate impacts of management-associated reductions in the supply of organic debris, primarily large woody debris, on fish habitat quality in each landtype association. A regulated supply of organic debris, including large woody debris (tree boles, rootwads, and large limbs) and small debris (needles, leaves, twigs, and branches), is vital to salmonids as a source of food, a control on sediment transport, a component of cover, and a contributor to higher pool-riffle ratios. The average resident time for logs in a stream is approximately 35 years (ranges from 0 to 100 years) dependent upon log species, the size of stream, and the average flow variation (Swanson and Lienkaemper, 1978). Some excellent research on the role and function of debris has been conducted by Swanson et al. (1976), Keller and Swanson (1979), Anderson et al. (1978), Everest and Meehan (1981) to name a few. The supply of organic debris on the Siuslaw is disrupted by clearcutting and subsequent short rotations in the streamside zone. The model simply calculates reductions in the area of this streamside "debris source zone". It then uses the ratio of the managed to the natural debris source zone to generate a "debris index".

The Debris Source Zone

The model assumes the natural debris source zone to be a strip 160 feet wide on each side of all fish streams and perennial tributaries. Thus, the debris source zone comprises the riparian area plus a 60-foot fringe of upland forest. The 160-foot width was chosen because the average site index for Douglas-fir (the dominant source of stream debris) on the Siuslaw is 160. Little stream debris should naturally come from outside a zone whose horizontal width equals the height of its dominant trees.

The model calculates reductions in the area of the debris source zone in two ways. First is a direct reduction by clearcutting in the zone itself. Clearcut acres are completely removed as a source of debris. The second way is an indirect reduction caused by clearcutting upslope from the zone. In this case, the zone acts as a leave strip. The debris supply is partially reduced, due to inefficiencies in implementing the leave strips correctly (see "Assumptions" below). The model sums both impacts to compute the area of active debris source zone remaining.

The model must account for the fact that it takes years for clearcut acres to regrow to a point where they can again supply significant amounts of organic debris to the stream. The model assumes that 20 years after cutting, the affected area will begin to supply organic debris.

The model underestimates organic debris impacts for two reasons. First, the major reductions of debris supply experienced in the numerous intermittent tributaries are not addressed. Such reductions surely affect food supplies and sediment transport to downstream habitat. Second, the model generously assumes that a 21-year-old forest supplies the necessary large woody debris to maintain its structural roles within the Forest's streams.

The model divides the acres of debris source zone remaining under management by the total acres of debris source zone. The quotient, the "debris zone ratio", is computed by the following equation, which is simplified here for discussion:

$$DZR = \frac{(R-r) - E(R-r)(u/U) + (F-f)}{R + F}$$

where DZR = debris zone ratio, R = total acres of riparian area, r = riparian acres harvested in the last 20 years, F = total acres of upland fringe, f = fringe acres harvested in the last 20 years, U = total upslope acres, u = upslope acres harvested in the last 20 years, and E = leave strip effectiveness. The left and right terms reflect direct reduction in the zone caused by harvesting riparian and fringe acres, respectively. The middle term reflects indirect reductions caused by harvesting immediately upslope. DZR is a dimensionless number between zero and one. Its value is one for undistrubed forest and zero when the debris source zone is completely clearcut.

The Debris Index

The model uses the debris zone ratio to calculate "debris index" for each landtype association. The equation used is:

$$DI = 1.14\ (0.88 - DZR)$$

where DI = debris index and DZR = debris zone ratio. The debris index is forced to zero until the debris zone ratio declines to below 0.88 (when more than 12 percent of the debris source zone is removed). The index is 1.00 when the debris zone ratio declines to zero (when the entire debris source zone is removed).

The rationale behind the lower threshold (0.88) is that native salmonids have adapted to some fluctuation in the supply of organic debris. The absence of an upper threshold indicates that disrupting the debris supply cannot by itself destroy the quality of salmonid habitat.

Assumptions

Several assumptions are used in the data for this portion of the model. These extra data were either based on limited studies or generated by opinion surveys (see Appendix II). The major assumptions are:

1. The debris source zone is as wide as the height of the dominant conifers.

2. Streamside leave strips have only 43 percent of the debris supply potential of the undisturbed forest. This inefficiency is caused by incremental reductions in leave strip effectiveness due to problems of site identification, layout, felling and yarding, slash burning, and windthrow.

3. Reduced debris supply to intermittent tributaries does not impact the quality of downstream habitat.

4. Debris supply potential is restored to natural levels when a forest stand exceeds 20 years in age.

5. Reductions in debris supply begin to affect habitat quality only when the area of the debris source zone for the landtype association is reduced by 12 percent (personal communication with Jim Sedell, 1975).

MANAGED HABITAT QUALITY: DEBRIS TORRENTS

The objective of this portion of the model is to estimte impacts of management-associated debris torrents on fish habitat quality in each landtype association. Limited inventories suggest that a small fraction of management-associated landslides produce large debris torrents. The typical large debris torrent scours an upstream segment to bedrock and buries a downstream segment beneath several feet of mud, rock, and debris. The model calculates the acres of fish stream scoured or buried by such large debris torrents. It also computes the reduction in habitat quality caused by debris torrents. Finally, it combines these data to generate a "debris torrent index".

Debris Torrent Impacts

The "MANAGED HABITAT QUANTITY" section explained how Bush's (1982) model estimates the frequency of landslides caused by clearcutting and road building. To compute the total number of management-associated landslides occurring in each landtype association for any time period, one simply enters the acres clearcut per risk category and the miles of road per construction category into the model. The model computes the totals for each category and then sums these totals. Inventories on the Mapleton Ranger District indicate that an average of 12.2 major debris torrents (those which travel more than 800 feet) are produced per 100 landslides. Recall that 8.4 of these reduce habitats by forming logjams. The remaining 3.8 reduce habitat quality by scouring and burying fish streams.

Opinion surveys (Appendix II) suggested that an average of 0.42 mile of fish stream is scoured or buried by each debris torrent. Stream width data (from stream surveys) were used to express the quantity of fish stream impacted per debris torrent in acres.

Opinion surveys also suggested that the average habitat quality of impacted streams is only 38 percent of the previous habitat quality condition. The surveys also suggested that the average fish stream recovers its previous habitat quality 15 years after the debris torrent occurs. This figure assumes that a source of large woody debris exists along the impacted stream. When such a source does not exist, recovery will take far longer. The model thus computes reduction in habitat quality as a function of elapsed time as follows:

Years Since Debris Torrent	Percent Reduction in Habitat Quality
1	62.0
2	57.6
3	53.1
4	48.7
5	44.3
6	39.9
7	35.4
8	31.0
9	26.6
10	22.1
11	17.7
12	13.3
13	8.9
14	4.4
15	0.0

The Debris Torrent Index

The model multiplies acres impacted by percent reduction in habitat quality for each of the 14 years preceding the year of analysis. The model then sums these products and computes the "debris torrent index" for the landtype association. The equation used is:

$$DTI = \frac{A-T}{A}$$

where DTI = debris torrent index, A = total acres of salmonid habitat, and T = torrent factor (sum of acre-quality products). The DTI is 1.00 only if no acres of fish stream have been impacted by debris torrents for 14 years in a row. The DTI would be 0.38 if every acre of fish stream were impacted by debris torrents in the same year. Of course, such a drastic disturbance would never even be approached over an entire landtype association.

No lower threshold exists for debris torrents because the severe scour and deposition produced by even the smallest debris torrent far exceeds the tolerance limit of any salmonid fish.

Assumptions

Several assumptions are used in the data for this portion of the model. These extra data were either based on limited studies or generated by opinion surveys (see Appendix II). The major assumptions are:

1. Debris torrents in fish streams result from 3.8 percent of management-associated landslides.

2. Each debris torrent scours or buries 0.42 mile of fish stream.

3. Each debris torrent reduces habitat quality by 62 percent.

4. Habitat quality is restored to previous levels in 15 years.

5. Adequate large woody debris is present for recruitment to provide channel structure following major debris torrents.

MANAGED HABITAT QUALITY: OVERALL INDEX

The objective of this portion of the model is to estimate the additive effects of accelerated sediment loads, increased water temperatures, disrupted debris supplies, and debris torrents on overall habitat quality in each landtype association. The model does this by computing a "watershed condition index". The equation used is:

$$WCI = (1.00 - SI - TI - 0.86DI)(DTI)$$

where WCI = watershed condition index, SI = sediment index, TI = temperature index, DI = debris index, and DTI = debris torrent index. Coefficients of 1.00 are implied for SI and TI because either sediment or temperature alone could destroy habitat quality if increased enough. The coefficient of 0.86 for the DI suggests that reducing the supply of organic debris to zero would by itself reduce habitat quality by 86 percent.

The WCI reflects the additive impacts of sediment, temperature, organic debris, and debris torrents on overall habitat quality. The WCI has a value between zero and one. It is multiplied by the natural habitat quality (number between 0 and 10, page 10) to derive the management-associated habitat quality. For example, if the WCI has a value of 0.60, then the management-associated habitat quality is 60 percent of the natural habitat quality.

The managed FHI is the product of management-associated quantity (reduced acres of habitat) times management-associated quality (reduced quality number). For example, suppose that natural habitat quantity was estimated at 2,000 acres and that the management-associated habitat quantity has been reduced to an estimated 1,500 acres. Suppose further that natural habitat quality was estimated to be 7.5 and management-associated quality has been reduced to an estimated 5.0. Natural and managed FHI are computed as follows:

1. Natural FHI 2,000 X 7.5 = 15,000
2. Managed FHI 1,500 X 5.0 = 7,500

Assumption

One additional assumption was needed to fill a gap in the data for this portion of the model. This data was obtained by personal communication with Jim Sedell (1982). The assumption is: if the debris source zone for the landtype association is eliminated, reductions in the supply of organic debris alone will reduce habitat quality by 86 percent.

DISCUSSION

The Siuslaw National Forest has useful quantitative new tool to aid in the management of land and water resources. Several important applications of the model have already been made. This section discusses some of these applications. It then lists some of the major strengths and limitations of the model. Finally, future data needs are identified.

Application

The most obvious benefit of the FHI is its ability to show the effects of forest management on salmonid habitat. Since the FHI is expressed as a single index number, comparisons between past, present, and future habitats can be simply made. Tradeoffs between timber and road management and salmonid habitat can be clearly and objectively assessed. The optimum mix of land allocations and management intensities can thus be more readily identified. We believe the FHI can be used for Forest, District, and basin planning. Its main beneficiaries are the forest land managers. The FHI will make their job of determining the best mix of resource investments and land allocations much easier.

The WCI can also be used to evaluate watershed conditions on the Forest. National direction requires that Forests do watershed condition inventories. Acre targets are disaggregated to the Forest each year. The watershed condition index can be determined for each of the 240 sixth code NFS watersheds on the Forest with no field survey required. The WCI is a cost-effective way to express watershed conditions in terms of the processes that most affect the quality of aquatic resources in the Coast Range. Watershed improvements can then be scheduled to focus on high-value watersheds having unsatisfactory watershed conditions.

The landtype associations are large blocks of land having distinct traits of lithology, land and channel form, and vegetation. These traits define distinct potentials for water and sediment yields, land hazards, timber production, and quantity and quality of fish habitat. The natural FHI permits a simple measure of the inherent value of the salmonid habitat to be made for each landtype association. Restoration and enhancement funds can be invested in the more productive stream systems.

Strengths and Limitations

Any resource model has its own set of strengths and limitations. Following is a list of the major strengths and limitations of the FHI model.

Strengths

The landtype association account for major variations in land and stream characteristics.

Natural habitat quality, sediment yield, and base flow are accurately inferred from simple map measurements of geomorphic parameters.

Field inventories covering large areas have produced reliable estimates of landslide rates and volumes and dry-ravel erosion.

The major factors affecting water temperature (stream exposure, solar angle, and base flow) are addressed.

Downstream temperature impacts caused by exposing perennial tributaries are considered.

Real world problems in implementing slope and stream protection measures are considered.

The model estimates the additive effects of all major resource processes on the quality and quantity of salmonid habitat.

Limitations

Effect of natural logjams on habitat quantity is not considered.

Mapping errors in the Soil Resource Inventory limit the reliability of landslide rate and volume estimates.

Channel erosion and surface road erosion are not considered.

The ease of heating small perennial tributaries versus larger fish streams is not addressed.

The effects of debris supply in intermittent tributaries and from landslides is not considered.

Differences in debris quality between tree species are not considered.

The lack of usable data for many resource processes and implementation problems required opinion surveys of field experts to generate the needed coefficients.

The model does not address cumulative impacts to large drainage basins because it is based on fourth-order watersheds.

The model assumes that all species and life stages of fish are affected equally.

FUTURE DATA NEEDS

A major benefit of the FHI model is the identification of the kind of data needed for decisionmaking. Most existing data either inadequately cover the interacting processes that the model addresses, or are site-specific and cannot be extrapolated to large land areas. The model should direct priorities for monitoring by the Forest, and research by experiment stations and universities, into areas most important for decision making. As new data is generated, the assumptions based on limited studies and opinion surveys will be replaced by hard data based on applied field investigation. Following is a list of general topics needing the attention of monitoring and research efforts:

1. The effect of natural logjams on available habitat quantity.

2. The percentage of landslides producing logjam migration barriers and debris torrents.

3. The spatial arrangement of logjam migration barriers and debris torrents in stream systems.

4. The longevity of logjam migration barriers, sediment flushing, temperature impacts, debris disruption, and debris torrent impacts.

5. Implementation success of leave areas, leave strips, modified roading practices, and directional felling.

6. Sediment yield and transport rates by landtype associations.

7. The rate of landsliding and debris torrents over large land areas and long time periods.

8. Refinement of soil and geomorphic mapping.

9. The effect of logging and slash burning on channel erosion and water temperatures.

10. Lower and upper thresholds for sediment, temperature, and debris impacts.

11. The rate of surface erosion from roads.

12. The input area and effect of debris supply on salmonid habitat quality.

13. The impact of debris torrents on salmonid habitat quality.

14. The effectiveness of removing migration barriers on salmonid habitat replenishment.

15. Recovery time of impacted streams without large woody debris input.

16. Debris budgets and influences on fish habitat quality by landtype associations.

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APPENDIX I

This appendix displays the output format of the Siuslaw Fish Habitat Index Model for one landtype association. The output variable definitions are displayed below for easy cross-reference with the output format.

Output Variable Definitions:

FHIN	Natural FHI
CFHI%	Current FHI as a percent of the natural FHI
QTN	Natural quantity (acres of fish habitat)
QLN	Natural quality index
MF	Miles of fish (broad and narrow) streams
MP	Miles of perennial streams
MI	Miles of intermittent streams
WAV	Mean fish stream width, feet
MNB	Miles of fish streams naturally blockaged
SYN	Natural sediment yield in cubic yards/year
A	Total acres
AU	Non-riparian acres
AR	Riparian acres
TA	Total acres Tentatively Available, Suitable, and Capable (TASC) for timber harvest
TAU	TASC non-riparian acres
TAR	TASC riparian acres
TLR-MS	TASC low risk acres, includes 100% low risk, 70% 421, 50% complex, 0% high risk, 0% ML, and any overlaying riparian, less marginal for safety areas
THR-MLS	TASC high risk acres, includes 0% low risk, 30% 421, 50% complex, 100% high risk, 100% ML, and any overlaying riparian, less marginal for safety and leave areas
TLRMS	TASC low risk marginal for safety acres
THRMS	TASC high risk maginal for safety acres
TML	TASC marginal leave acres, all considered high risk
TMS	TASC marginal for safety acres
DEC	Decade, e.g. 1941-1950 = 1940's

The following variables contain average annual values for the current decade:

FHIM	Managed FHI
%	Managed FHI as a percent of the natural FHI
QTM	Managed quantity (acres of fish habitat)
AB	Acres of fish streams blocked by logjams
SLD	Number of accelerated slides
ACU	Acres clearcut, non-riparian
%TAU	Acres clearcut, non-riparian as a percent of TASC acres, non-riparian
ACR	Acres clearcut, riparian
TLJ	Total logjams existing
LJO	Logjams occurring
LJB	Logjams breaking
TBK	Total miles of fish stream blocked by logjams

BK1	Miles of fish streams remaining blocked if worst blockages were removed at a rate of one per year
BK	Miles of fish streams remaining blocked if worst blockages were removed at a rate of two per year
1FR	Acres of fish streams freed if worst blockage was removed
QLM	Managed quality index
WI	Watershed index
SI	Sediment index
TI	Temperature index
DI	Debris index
SLOUT	Acres of sluiced-out fish habitat
SYM	Accelerated sediment yield in cubic yards (surface and slide)

LANDTYPE ASSOCIATION F

1. SOIL YIELD TABLES ARE FOR LEAVE TS AND ML PLUS [illegible] LP AND 22.6 [illegible].
2. MAXIMUM ALLOWABLE CLEARCUT ACRES PER YEAR = [illegible].
3. BURN PRESCRIPTION = NOT.
4. LOGJAMS REMOVED PER YEAR = 0.
5. NATURAL BLOCKAGES REMOVED PER YEAR = 2.
6. STREAM ENHANCEMENTS PER YEAR = 2.

FRIN	CFRI%	QTN	QLN	MF	MP	MI	MA	MAB	SYN
2176	61	437.62	5.2	215.1	276.2	810.1	15.8	8.5	285[illegible]

ACRES	A	AU	AR	TA	TAU	TAR	TLR-AS	TLR-AIS	TML	TNS	30%TAU
	93929.6	91715.4	12111.2	98767.2	76716.7	12[illegible]	[illegible]	[illegible]	1117.9	19[illegible]1	23015.0

DECADE MEANS

DEC	FRIM	%	ACU	YEAR	ACR	QTN	AF	SLT	TLU	LJC	LJR	TEA	BK1	BF	[illegible]	QLN	A1	S1	F1	DI	SLOUT	SYN
1940'S	2175	100	-4	2	2	437.7	[illegible]	2.3	[illegible]	[illegible]	[illegible]	2	2	[illegible]	[illegible].1	4.57	1.000	0.00[illegible]	[illegible]	[illegible]	0.0	177.8
1950'S	1997	97	433	6	64	413.4	[illegible]	25.9	[illegible]	[illegible]	0	12	2	1	8.9	4.[illegible]	0.325	0.274	0.2[illegible]	[illegible]	1.0	14[illegible]
1960'S	867	40	970	12	147	311.5	126.3	57.[illegible]	[illegible]1	[illegible]	1	[illegible]	24	[illegible]	16.3	2.75	0.575	0.3[illegible]	0.287	[illegible]	16.2	[illegible]
1970'S	1063	49	749	12	68	298.8	141.2	33.7	[illegible]	2	4	[illegible]	22	4	17.2	[illegible]	0.741	0.203	0.275	0.104	19.1	10242.[illegible]
1980'S	235	11	4208	33	0	295.3	142.5	78.7	[illegible]	6	3	72	25	1[illegible]	16.3	[illegible]	0.184	0.407	0.210	0.233	17.2	[illegible]
1990'S	959	44	43	1	1	312.9	124.9	2.9	[illegible]1	[illegible]	4	51	18	5	17.4	[illegible]	0.33[illegible]	0.0[illegible]	0.097	0.255	15.6	[illegible]3.0
2000'S	1629	64	653	8	0	395.0	3[illegible]	9.4	11	1	2	[illegible]	1	[illegible]	14.2	4.[illegible]	0.32[illegible]	0.302	0.0[illegible]	0.0[illegible]	[illegible]	[illegible]70.2
2010'S	1752	81	0	0	312	417.4	27.4	5.8	7	2	1	13	2	[illegible]	11.6	4.27	0.882	0.002	0.118	[illegible]	2.6	432.[illegible]
2020'S	1258	58	1604	2	7	256.2	51.6	24.2	1	2	1	25	3	[illegible]	[illegible]	[illegible]	0.[illegible]	0.3[illegible]	0.147	[illegible]	4.2	[illegible]

APPENDIX II

This appendix displays the questionnaire that was administered to a panel of professionals knowledgeable in the area of forestry and fisheries management, and the results obtained. The Delphi technique was used as the method for systematically developing a consensus among experts. By developing a consensus, Delphi precludes the necessity to choose among estimates, since the "best" estimate is arrived at. See the compendium entitled The Delphi Method (Linstone and Turoff 1975) for a detailed discussion of the method and examples of its application.

The results of the questionnaire are displayed on each question. Questions 1-5 were administered to USDA Forest Service personnel, working in the central Oregon Coast Range (Tillamook to Reedsport), in the timber management program. The group of experts polled on questions 1-5 included foresters, forestry technicians, engineers, soil scientists, hydrologists, and fish biologists. The number of experts responding to each question is noted at the top of the question. The average of all respondents has been placed in the appropriate blank, and the standard deviation placed in parenthesis.

Questions 6-21 were handled a little differently. Twenty-two experts were included in the panel. Twelve members were fishery biologists, including biologists from the Forest Service, Oregon Department of Fish and Wildlife, and Bureau of Land Management. Five panel members were hydrologists working for the Forest Service, and the remaining five panel members were soil scientists working for the Forest Service. All members of the panel had worked in the central Oregon Coast Range and had experience in working with problems associated the management of the timber and fisheries resource.

The design of the instruments used in Questions 6-21 follows that utilized by McNutt (1976). The analysis of this type of instrument employs Bayesian analysis through the use of "Bayes' Theorem". No questions on multiple events were presented so a full analysis of the type used by McNutt is not possible. Calvin (1981) in his report on the FHI model design states:

> "McNutt's technique is useful in calculating the probabilities of stream conditions given the event. This method was used in calculating these probabilities for each expert answering the questionnaire. The individual probabilities were averaged for the entire panel. The probabilities are then used to estimate an average condition, given the event by calculating a weighted average condition, where the weights are the mean probabilities. For example, with the question on "Percentage of Logjams Forming Migration Barriers", a weighted average of the number of major logjams forming significant fish barriers would be calculated by weighting the mid points of each class, i.e. 10, 30, 50, 70, and 90, by the mean probabilities over all individuals in the analysis. This would give the number of major logjams, out of 100 created by sluiceouts, forming significant fish migration barriers."

The mean probabilities and the overall mean rankings are displayed on each question.

Please answer the questions on the following pages by drawing on <u>all</u> your field experience on the Siuslaw National Forest.

Question 1

Number of Respondents 26

Mean (Standard Deviation)

LEAVE AREAS (landsliding)

Leave areas are retained on unstable headwalls and stream-adjacent slopes to minimize landsliding due to timber harvest. Specifically, the objective of each leave area is to maintain at least 90% of existing vegetation in the unstable portion of the site. Given that the unstable portion of the site averages 2.5 acres in size, please answer the following questions to the nearest 5.

1. Of 100 unstable sites needing leave areas, how many (on the average) are correctly identified and incorporated into the final sale contract? 73 (16.3)

2. Of 100 leave areas identified in sale contracts, how many (on the average) are accurately located and flagged on the ground to meet the objective? 80.8 (14.3)

3. Of 100 accurately located and flagged leave areas, how many (on the average) still meet the objective after felling and yarding?

   (a) if a 2.5 acre leave area is retained? 78.8 (13.7)

   (b) if a 5.0 acre leave area is retained? 84.2 (13.1)

4. Of 100 leave areas meeting the objective after felling and yarding, how many (on the average) still meet the objective after slash burning?

   (a) if a 2.5 acre leave area is retained? 69.8 (17.8)

   (b) if a 5.0 acre leave area is retained? 82.1 (16.8)

5. Of 100 leave areas meeting the objective after slash burning, how many (on the average) still meet the objective 10 years later (blowdown)?

   (a) if a 2.5 acre leave area is retained? 72.1 (23.8)

   (b) if a 5.0 acre leave area is retained? 77.5 (23.8)

Question 2

Number of Respondents 28

Mean (Standard Deviation)

LEAVE STRIPS (erosion)

Leave strips are retained on steep slopes along V-notched headwater streams to minimize sedimentation from dry ravel and streambank erosion due to timber harvest. Specifically, the objective of these leave strips is to maintain existing vegetation along the immediate streambank and complete ground cover under the entire leave strip. Please answer the following questions to the nearest 5.

1. If 100 acres of leave strips are needed to meet the objective, how many acres (on the average) are correctly identified and incorporated into the final sale contract? 84.3 (13.1)

2. Of 100 acres of leave strips identified in sale contracts, how many acres (on the average) are accurately located and flagged on the ground? 85.0 (16.8)

3. Of 100 acres of accurately located leave strips, how many acres (on the average) still remain to meet the objective after felling and yarding? 80.0 (17.6)

4. Of 100 acres of leave strips meeting the objective after felling and yarding, how many acres (on the average) still remain to meet the objective after slash burning? 77.3 (17.7)

5. Of 100 acres of leave strips meeting the objective after slash burning, how many acres (on the average) still remain to meet the objective 5 years later (blowdown)? 78.9 (21.2)

Question 3

Number of Respondents 26

Mean (Standard Deviation)

LEAVE STRIPS (temperature)

Leave strips are retained along perennial streams primarily to minimize water temperature increases due to timber harvest. Specifically, the objective of these leave strips is to maintain existing shade on the perennial streams during the summer. Please answer the following questions to the nearest 5.

1. If 100 acres of leave strips are needed to meet the objective, how many acres (on the average) are correctly identified and incorporated into the final sale contract? 87.7 (16.9)

2. Of 100 acres of leave strips identified in sale contracts, how many acres (on the average) are accurately located and flagged on the ground? 83.0 (18.5)

3. Of 100 acres of accurately located leave strips, how many acres (on the average) still remain to meet the objective after felling and yarding? 78.0 (14.0)

4. Of 100 acres of leave strips meeting the objective after felling and yarding, how many acres (on the average) still remain to meet the ofjective after slash burning? 80.3 (12.1)

5. Of 100 acres of leave strips meeting the object after slash burning, how many acres (on the average) still remain to meet the objective 5 years later (blowdown)? 81.2 (16.2)

Question 4

Number of Respondents 27

Mean (Standard Deviation)

UPHILL DIRECTIONAL FELLING

Uphill directional felling is used on steep slopes along V-notched headwater streams to minimize sedimentation from dry ravel erosion due to slash burning. Specifically, the objective of the uphill felling is to minimize additions of woody debris to the stream channel. Given an average stream-adjacent slope of 85%, please answer the following questions to the nearest 5.

1. If 100 acres of uphill directional felling are needed to meet the objective, how many acres (on the average) are correctly identified and incorporated into the final sale contract? 79.8 (17.8)

2. Of 100 acres identified for directional felling in sale contracts, how many acres (on the average) are accurately located on the ground? 80.3 (20.0)

3. How much woody debris (on the average) is deposited in the stream channel during felling and yarding if uphill directional felling is used (express as a percent of the amount deposited if conventional downhill felling were used):

   (a) if the trees are jacked uphill? 37.0 (20.7) percent

   (b) if the trees are lined uphill? 31.3 (28.6) percent

Question 5

Number of Respondents 23

Mean (Standard Deviation)

LANDSLIDES FROM ROADS

Landsliding from roads attributable to design errors, plumbing failures, misuse, and lack of maintenance occurs at some constant minimal rate (considering the District as a whole). There are two periods when sliding accelerates beyond this minimal rate: (1) immediately after construction, through slope readjustment; and (2) several years later, through rotting of organic material in fills and sidecast.

1. Please estimate relative landslide volume rates as a percentage of the "organic rot" rate (to the nearest 5 percent):

   a. Minimal rate 22.8 (18.6)
   b. Slope readjustment rate 57.2 (51.2)
   c. Organic rot rate 100

2. Please estimate the time period since construction that sliding occurs, as associated with:

   a. Slope readjustment: 3.3 (2.0) years since construction.
   b. Organic rot: 12.5 (5.2) years since construction.

3. Do you believe the rates and/or time periods vary significantly between different areas of your District or the Forest? If yes, explain what you think the variance is.

Written Comments

Please answer the circled questions and question 11 on each of the pages by drawing on all your field experience in the central Oregon Coast Range (Tillamook to Reedsport). For each circled question, you have $100 to wager. Wager the entire sum for each circled question.

Question 6

Number of Respondents 22

PERCENTAGE OF LOGJAMS FORMING MIGRATION BARRIERS

Of 100 major logjams created by major debris torrents (sluiceouts), how many form significant fish migration barriers (i.e., those that would block at least 50% of all migrating fish species in an average climatic year)? 44.13%

1. I wager $____ that 0-20 major logjams, and $____ that 20-40 major logjams, form such barriers.

2. I wager $____ that 0-20 major logjams, and $____ that 40-60 major logjams, form such barriers.

3. I wager $____ that 0-20 major logjams, and $____ that 60-80 major logjams, form such barriers.

4. I wager $____ that 0-20 major logjams, and $____ that 80-100 major logjams, form such barriers.

5. I wager $____ that 20-40 major logjams, and $____ that 40-60 major logjams, form such barriers.

6. I wager $____ that 20-40 major logjams, and $____ that 60-80 major logjams, form such barriers.

7. I wager $____ that 20-40 major logjams, and $____ that 80-100 major logjams, form such barriers.

8. I wager $____ that 40-60 major logjams, and $____ that 60-80 major logjams, form such barriers.

9. I wager $____ that 40-60 major logjams, and $____ that 80-100 major logjams, form such barriers.

10. I wager $____ that 60-80 major logjams, and $____ that 80-100 major logjams, form such barriers.

11. Rank each of the following according to likelihood of forming such a barrier. A ranking of 1 is most likely, and a ranking of 5 is least likely.

0-20	major logjams	3
20-40	major logjams	2
40-60	major logjams	1
60-80	major logjams	4
80-100	major logjams	5

Question 7

Number of Respondents 22

BLOCKAGE EFFICIENCY OF MIGRATION BARRIERS

For logjams that form significant fish migration barriers (i.e., those that would block at least 50% of all migrating fish species in an average climatic year), what percent of all migrating fish (on the average) would be barred from migration in an average climatic year? 50.95%

1. I wager $____ that 0-20 percent, and $____ that 20-40 percent, would be barred.

2. I wager $____ that 0-20 percent, and $____ that 40-60 percent, would be barred.

3. I wager $____ that 0-20 percent, and $____ that 60-80 percent, would be barred.

4. I wager $____ that 0-20 percent, and $____ that 80-100 percent, would be barred.

5. I wager $____ that 20-40 percent, and $____ that 40-60 percent, would be barred.

6. I wager $____ that 20-40 percent, and $____ that 60-80 percent, would be barred.

7. I wager $____ that 20-40 percent, and $____ that 80-100 percent, would be barred.

8. I wager $____ that 40-60 percent, and $____ that 60-80 percent, would be barred.

9. I wager $____ that 40-60 percent, and $____ that 80-100 percent, would be barred.

10. I wager $____ that 60-80 percent, and $____ that 80-100 percent, wouold be barred.

11. Rank each of the following according to likelihood of percent of fish barred. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-20 percent 5
    20-40 percent 3
    40-60 percent 1
    60-80 percent 2
    80-100 percent 4

Question 8

Number of Respondents 22

MILES BLOCKED PER MIGRATION BARRIER

For each logjam that forms a significant fish migration barrier (i.e., one that would block at least 50% of all migrating fish species in an average climatic year), how many miles of fish habitat (including winter spawning areas available only during higher flows) are blocked, on the average? .45 mi.

1. I wager $____ that 0.0-0.2 mile, and $____ that 0.2-0.4 mile, are blocked.

2. I wager $____ that 0.0-0.2 mile, and $____ that 0.4-0.6 mile, are blocked.

3. I wager $____ that 0.0-0.2 mile, and $____ that 0.6-0.8 mile, are blocked.

4. I wager $____ that 0.0-0.2 mile, and $____ that more than 0.8 mile, are blocked.

5. I wager $____ that 0.2-0.4 mile, and $____ that 0.4-0.6 mile, are blocked.

6. I wager $____ that 0.2-0.4 mile, and $____ that 0.6-0.8 mile, are blocked.

7. I wager $____ that 0.2-0.4 mile, and $____ that more than 8.8 mile, are blocked.

8. I wager $____ that 0.4-0.6 mile, and $____ that 0.6-0.8 mile, are blocked.

9. I wager $____ that 0.4-0.6 mile, and $____ that more than 0.8 mile, are blocked.

10. I wager $____ that 0.6-0.8 mile, and $____ that more than 0.8 mile, are blocked.

11. Rank each of the following according to likelihood of miles blocked. A ranking of 1 is most likely, and a ranking of 5 is least likely.

0.0-0.2 mile	4
0.2-0.4 mile	2
0.4-0.6 mile	1
0.6-0.8 mile	3
More than 0.8 mile	5

Question 9

Number of Respondents 22

LONGEVITY OF MIGRATION BARRIERS

For logjams that form significant fish migration barriers (i.e., those that would initially block at least 50% of all migrating fish species in an average climatic year), how long will it take (on the average) for available fish passage to be naturally restored to 80-100% of pre-logjam fish passage? 12.57 yrs.

1. I wager $____ that it will take 0-5 years, and $____ that it will take 5-10 years.
2. I wager $____ that it will take 0-5 years, and $____ that it will take 10-15 years.
3. I wager $____ that it will take 0-5 years, and $____ that it will take 15-20 years.
4. I wager $____ that it will take 0-5 years, and $____ that it will take more than 20 years.
5. I wager $____ that it will take 5-10 years, and $____ that it will take 10-15 years.
6. I wager $____ that it will take 5-10 years, and $____ that it will take 15-20 years.
7. I wager $____ that it will take 5-10 years, and $____ that it will take more than 20 years.
8. I wager $____ that it will take 10-15 years, and $____ that it will take 15-20 years.
9. I wager $____ that it will take 10-15 years, and $____ that it will take more than 20 years.
10. I wager $____ that it will take 15-20 years, and $____ that it will take more than 20 years.
11. Rank the following according to likelihood of time to recover. A ranking of 1 is most likely, and a ranking of 5 is least likely.

0-5 years	5
5-10 years	3
10-15 years	1
15-20 years	2
More than 20 years	4

Question 10

Number of Respondents 22

"STACKING" OF MIGRATION BARRIERS

Given a 25,000 acre "undisturbed" forested watershed that is 90% high risk soils and has 50 miles of anadromous fish streams. Assume the entire watershed is clearcut and roaded all at once, and that resulting debris torrents (sluiceouts) create 125 logjams that constitute significant fish migration barriers. Realizing that these logjams would "stack up" one behind another in the stream network so that many logjams form behind others, how many of the 50 miles of anadromous streams would be blocked after the 125 logjams had formed? 25.69 mi.

1. I wager $____ that 0-10 miles, and $____ that 10-20 miles, would be blocked.
2. I wager $____ that 0-10 miles, and $____ that 20-30 miles, would be blocked.
3. I wager $____ that 0-10 miles, and $____ that 30-40 miles, would be blocked.
4. I wager $____ that 0-10 miles, and $____ that 40-50 miles, would be blocked.
5. I wager $____ that 10-20 miles, and $____ that 20-30 miles, would be blocked.
6. I wager $____ that 10-20 miles, and $____ that 30-40 miles, would be blocked.
7. I wager $____ that 10-20 miles, and $____ that 40-50 miles, would be blocked.
8. I wager $____ that 20-30 miles, and $____ that 30-40 miles, would be blocked.
9. I wager $____ that 20-30 miles, and $____ that 40-50 miles, would be blocked.
10. I wager $____ that 30-40 miles, and $____ that 40-50 miles, would be blocked.
11. Rank each of the following according to likelihood of miles blocked. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-10 miles __5__
    10-20 miles __2__
    20-30 miles __1__
    30-40 miles __3__
    40-50 miles __4__

Question 11

Number of Respondents 22

PERCENTAGE OF SLUICEOUTS HEAVILY IMPACTING FISH STREAMS

Major debris torrents (sluiceouts) often heavily impact stream channels by severely scouring an upstream segment and burying a downstream segment with sediment and debris. Of 100 major sluiceouts, how many have such heavy impacts to habitat in fish-bearing streams? 53.76%

1. I wager $____ that 0-20 major sluiceouts, and $____ that 20-40 major sluiceouts, cause such alteration.

2. I wager $____ that 0-20 major sluiceouts, and $____ that 40-60 major sluiceouts, cause such alteration.

3. I wager $____ that 0-20 major sluiceouts, and $____ that 60-80 major sluiceouts, cause such alteration.

4. I wager $____ that 0-20 major sluiceouts, and $____ that 80-100 major sluiceouts, cause such alteration.

5. I wager $____ that 20-40 major sluiceouts, and $____ that 40-60 major sluiceouts, cause such alteration.

6. I wager $____ that 20-40 major sluiceouts, and $____ that 60-80 major sluiceouts, cause such alteration.

7. I wager $____ that 20-40 major sluiceouts, and $____ that 80-100 major sluiceouts, cause such alteration.

8. I wager $____ that 40-60 major sluiceouts, and $____ that 60-80 major sluiceouts, cause such alteration.

9. I wager $____ that 40-60 major sluiceouts, and $____ that 80-100 major sluiceouts, cause such alteration.

10. I wager $____ that 60-80 major sluiceouts, and $____ that 80-100 major sluiceouts, cause such alteration.

11. Rank each of the following according to likelihood of causing such heavy impacts. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-20 Major sluiceouts 5
    20-40 Major sluiceouts 3
    40-60 Major sluiceouts 2
    60-80 Major sluiceouts 1
    80-100 Major sluiceouts 4

Question 12

Number of Respondents 22

POST-SLUICEOUT HABITAT CONDITION

If pre-sluiceout fish habitat condition were assumed to be 100%, what would post-sluiceout habitat condition be? 37.57%

1. I wager $____ that it would be 0-20%, and $____ that it would be 20-40%.
2. I wager $____ that it would be 0-20%, and $____ that it would be 40-60%.
3. I wager $____ that it would be 0-20%, and $____ that it would be 60-80%.
4. I wager $____ that it would be 0-20%, and $____ that it would be 80-100%.
5. I wager $____ that it would be 20-40%, and $____ that it would be 40-60%.
6. I wager $____ that it would be 20-40%, and $____ that it would be 60-80%.
7. I wager $____ that it would be 20-40%, and $____ that it would be 80-100%.
8. I wager $____ that it would be 40-60%, and $____ that it would be 60-80%.
9. I wager $____ that it would be 40-60%, and $____ that it would be 80-100%.
10. I wager $____ that it would be 60-80%, and $____ that it would be 80-100%.
11. Rank each of the following according to likelihood of post-sluiceout habitat condition. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-20% 2
    20-40% 1
    40-60% 3
    60-80% 4
    80-100 5

Question 13

Number of Respondents 22

MILES IMPACTED PER SLUICEOUT

On the average, how many miles of stream providing fish habitat are heavily impacted by each major sluiceout? .42 mi.

1. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.2-0.4 mile, are so altered.

2. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.4-0.6 mile, are so altered.

3. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.6-0.8 mile, are so altered.

4. I wager $_____ that 0.0-0.2 mile, and $_____ that more than 0.8 mile, are so altered.

5. I wager $_____ that 0.2-0.4 mile, and $_____ that 0.4-0.6 mile, are so altered.

6. I wager $_____ that 0.2-0.4 mile, and $_____ that 0.6-0.8 mile, are so altered.

7. I wager $_____ that 0.2-0.4 mile, and $_____ that more than 0.8 mile, are so altered.

8. I wager $_____ that 0.4-0.6 mile, and $_____ that 0.6-0.8 mile, are so altered.

9. I wager $_____ that 0.4-0.6 mile, and $_____ that more than 0.8 mile, are so altered.

10. I wager $_____ that 0.6-0.8 mile, and $_____ that more than 0.8 miles, are so altered.

11. Rank each of the following according to likelihood of miles so altered. A ranking of 1 is most likely, and a ranking of 5 is least likely.

0.0-0.2 mile	3
0.2-0.4 mile	2
0.4-0.6 mile	1
0.6-0.8 mile	4
More than 0.8 mile	5

Question 14

Number of Respondents 22

LONGEVITY OF SLUICEOUT IMPACT

On the average, how long will it take post-sluiceout fish habitat condition to return to 80-100% of pre-sluiceout habitat condition? 15.79 yrs.

1. I wager $_____ that it will take 0-5 years, and $_____ that it will take 5-10 years.

2. I wager $_____ that it will take 0-5 years, and $_____ that it will take 10-15 years.

3. I wager $_____ that it will take 0-5 years, and $_____ that it will take 15-20 years.

4. I wager $_____ that it will take 0-5 years, and $_____ that it will take more than 20 years.

5. I wager $_____ that it will take 5-10 years, and $_____ that it will take 10-15 years.

6. I wager $_____ that it will take 5-10 years, and $_____ that it will take 15-20 years.

7. I wager $_____ that it will take 5-10 years, and $_____ that it will take more than 20 years.

8. I wager $_____ that it will take 10-15 years, and $_____ that it will take 15-20 years.

9. I wager $_____ that it will take 10-15 years, and $_____ that it will take more than 20 years.

10. I wager $_____ that it will take 15-20 years, and $_____ that it will take more than 20 years.

11. Rank the following according to likelihood of time to recover. A ranking of 1 is most likely, and a ranking of 5 is least likely.

0-5 years	5
5-10 years	4
10-15 years	2
15-20 years	1
More than 20 years	3

Question 15

Number of Respondents 22

MILES BOTH BLOCKED AND SCOURED

On the average, for each logjam that forms a significant fish migration barrier (i.e., one that would block at least 50% of all migrating fish species in an average climatic year), how many miles of fish habitat are heavily impacted (scoured and buried) by sluiceouts, as well as blocked? .51 mi.

1. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.2-0.4 miles, are blocked.
2. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.4-0.6 miles, are blocked.
3. I wager $_____ that 0.0-0.2 mile, and $_____ that 0.6-0.8 miles, are blocked.
4. I wager $_____ that 0.0-0.2 mile, and $_____ that more than 0.8 miles, are blocked.
5. I wager $_____ that 0.2-0.4 mile, and $_____ that 0.4-0.6 miles, are blocked.
6. I wager $_____ that 0.2-0.4 mile, and $_____ that 0.6-0.8 miles, are blocked.
7. I wager $_____ that 0.2-0.4 mile, and $_____ that more than 0.8 miles, are blocked.
8. I wager $_____ that 0.4-0.6 mile, and $_____ that 0.6-0.8 miles, are blocked.
9. I wager $_____ that 0.4-0.6 mile, and $_____ that more than 0.8 miles, are blocked.
10. I wager $_____ that 0.6-0.8 mile, and $_____ that more than 0.8 miles, are blocked.
11. Rank each of the following according to likelihood of miles both blocked and scoured/buried. A ranking of 1 is most likely, and ranking of 5 is least likely.

    0.0-0.2 mile 5
    0.2-0.4 mile 2
    0.4-0.6 mile 1
    0.6-0.8 mile 3
    More than 0.8 mile 4

Question 16

Number of Respondents 22

LOWER SEDIMENT THRESHOLD

Given a 25,000 acre forested watershed. Assuming "undisturbed" basin-wide salmonid habitat quality to be 100%, by how much must basin-wide sediment loading increase over the "undisturbed" loading rate to lower the basin-wide salmonid habitat quality to 95%? 24.94%

1. I wager $____ that it must increase by 0-10%, and $____ that it must increase by 10-20%.

2. I wager $____ that it must increase by 0-10%, and $____ that it must increase by 20-30%.

3. I wager $____ that it must increase by 0-10%, and $____ that it must increase by 30-40%.

4. I wager $____ that it must increase by 0-10%, and $____ that it must increase by 40-50%.

5. I wager $____ that it must increase by 10-20%, and $____ that it must increase by 20-30%.

6. I wager $____ that it must increase by 10-20%, and $____ that it must increase by 30-40%.

7. I wager $____ that it must increase by 10-20%, and $____ that it must increase by 40-50%.

8. I wager $____ that it must increase by 20-30%, and $____ that it must increase by 30-40%.

9. I wager $____ that it must increase by 20-30%, and $____ that it must increase by 40-50%.

10. I wager $____ that it must increase by 30-40%, and $____ that it must increase by 40-50%.

11. Rank each of the following according to likelihood of required increase in sediment loading. A ranking of 1 is most likely, and ranking of 5 is least likely.

0-10% increase	4
10-20% increase	2
20-30% increase	1
30-40% increase	3
40-50% increase	5

Question 17

Number of Respondents 22

UPPER SEDIMENT THRESHOLD

Given a 25,000 acre forested watershed. Assuming "undisturbed" basin-wide salmonid habitat quality to be 100%, by how much must basin-wide sediment loading increase over the "undisturbed" loading rate to lower the basin-wide salmonid habitat quality to 0-20%? 331.2%

1. I wager $____ that it must increase by 100%, and $____ that it must increase by 200%.

2. I wager $____ that it must increase by 100%, and $____ that it must increase by 300%.

3. I wager $____ that it must increase by 100%, and $____ that it must increase by 400%.

4. I wager $____ that it must increase by 100%, and $____ that it must increase by 500%.

5. I wager $____ that it must increase by 200%, and $____ that it must increase by 400%.

6. I wager $____ that it must increase by 200%, and $____ that it must increase by 400%.

7. I wager $____ that it must increase by 200%, and $____ that it must increase by 500%.

8. I wager $____ that it must increase by 300%, and $____ that it must increase by 400%.

9. I wager $____ that it must increase by 300%, and $____ that it must increase by 500%.

10. I wager $____ that it must increase by 400%, and $____ that it must increase by 500%.

11. Rank each of the following according to likelihood of required increase in sediment loading. A ranking of 1 is most likely, and a ranking of 5 is least likely.

100% increase	5
200% increase	4
300% increase	1
400% increase	2
500% increase	3

Question 18

Number of Respondents 22

LOWER TEMPERATURE THRESHOLD

Cool summer water temperatures are essential for maintaining salmonid habitat quality. The potential for temperature increases depends on the amount of shade removed on perennial streams. Given a 25,000 acre forested watershed with a basin-wide salmonid habitat quality of 100%. By how much must the total amount of shade on the perennial streams of the watershed be reduced to lower the basin-wide salmonid habitat quality to 95%? 14.98%

1. I wager $____ that it must be reduced by 0-5%, and $____ that it must be reduced by 5-10%.

2. I wager $____ that it must be reduced by 0-5%, and $____ that it must be reduced by 10-15%.

3. I wager $____ that it must be reduced by 0-5%, and $____ that it must be reduced by 15-20%.

4. I wager $____ that it must be reduced by 0-5%, and $____ that it must be reduced by 20-25%.

5. I wager $____ that it must be reduced by 5-10%, and $____ that it must be reduced by 10-15%.

6. I wager $____ that it must be reduced by 5-10%, and $____ that it must be reduced by 15-20%.

7. I wager $____ that it must be reduced by 5-10%, and $____ that it must be reduced by 20-25%.

8. I wager $____ that it must be reduced by 10-15%, and $____ that it must be reduced by 15-20%.

9. I wager $____ that it must be reduced by 10-15%, and $____ that it must be reduced by 20-25%.

10. I wager $____ that it must be reduced by 15-20%, and $____ that it must be reduced by 20-25%.

11. Rank each of the following according to likelihood of required reduction in shade. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-5% reduction 5
    5-10% reduction 4
    10-15% reduction 1
    15-20% reduction 2
    20-25% reduction 3

Question 19

Number of Respondents 22

UPPER TEMPERATURE THRESHOLD

Cool summer water temperatures are essential for maintaining salmonid habitat quality. The potential for temperature increases depends on the amount of shade removed on perennial streams. Given a 25,000 acre forested watershed with a basin-wide salmonid habitat quality of 100%. By how much must the total amount of shade on the perennial streams of the watershed be reduced to lower the basin-wide salmonid habitat quality to 0-20%? 72.98%

1. I wager $____ that it must be reduced by 50-60%, and $____ that it must be reduced by 60-70%.

2. I wager $____ that it must be reduced by 50-60%, and $____ that it must be reduced by 70-80%.

3. I wager $____ that it must be reduced by 50-60%, and $____ that it must be reduced by 80-90%.

4. I wager $____ that it must be reduced by 50-60%, and $____ that it must be reduced by 90-100%.

5. I wager $____ that it must be reduced by 60-70%, and $____ that it must be reduced by 70-80%.

6. I wager $____ that it must be reduced by 60-70%, and $____ that it must be reduced by 80-90%.

7. I wager $____ that it must be reduced by 60-70%, and $____ that it must be reduced by 90-100%.

8. I wager $____ that it must be reduced by 70-80%, and $____ that it must be reduced by 80-90%.

9. I wager $____ that it must be reduced by 70-80%, and $____ that it must be reduced by 90-100%.

10. I wager $____ that it must be reduced by 80-90%, and $____ that it must be reduced by 90-100%.

11. Rank each of the following according to likelihood of required reduction in shade. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    50-60% reduction 5
    60-70% reduction 2
    70-80% reduction 1
    80-90% reduction 3
    90-100% reduction 4

Question 20

Number of Respondents 22

LOWER DEBRIS THRESHOLD

A regulated supply of woody organic debris is important for maintaining salmonid habitat quality as a food source, a regulator of sediment transport, and a contributor to instream cover and a higher pool-riffle ratio. Given a 25,000 acre forested watershed with a basin-wide salmonid habitat quality of 100%. By how much must the supply of woody organic debris to the stream system be reduced to lower the basin-wide salmonid habitat quality to 95% 23.57%

1. I wager $____ that it must be reduced by 0-10%, and $____ that it must be reduced by 10-20%.

2. I wager $____ that it must be reduced by 0-10%, and $____ that it must be reduced by 20-30%.

3. I wager $____ that it must be reduced by 0-10%, and $____ that it must be reduced by 30-40%.

4. I wager $____ that it must be reduced by 0-10%, and $____ that it must be reduced by 40-50%.

5. I wager $____ that it must be reduced by 10-20%, and $____ that it must be reduced by 20-30%.

6. I wager $____ that it must be reduced by 10-20%, and $____ that it must be reduced by 30-40%.

7. I wager $____ that it must be reduced by 10-20%, and $____ that it must be reduced by 40-50%.

8. I wager $____ that it must be reduced by 20-30%, and $____ that it must be reduced by 30-40%.

9. I wager $____ that it must be reduced by 20-30%, and $____ that it must be reduced by 40-50%.

10. I wager $____ that it must be reduced by 30-40%, and $____ that it must be reduced by 40-50%.

11. Rank each of the following according to likelihood of required reduction in debris supply. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-10% reduction 5
    10-20% reduction 2
    20-30% reduction 1
    30-40% reduction 3
    40-50% reduction 4

Question 21

Number of Respondents 22

UPPER DEBRIS THRESHOLD

A regulated supply of woody organic debris is important for maintaining salmonid habitat quality as a food source, a regulator of sediment transport, and a contributor to instream cover and a higher pool-riffle ratio. Given a 25,000 acre forested watershed with a basin-wide salmonid habitat quality of 100%. If the supply of woody organic debris to the stream system were completely stopped over the entire basin, to what level would salmonid habitat quality be reduced? 52.12%

1. I wager $____ that it would be 0-20%, and $____ that it would be 20-40%.
2. I wager $____ that it would be 0-20%, and $____ that it would be 40-60%.
3. I wager $____ that it would be 0-20%, and $____ that it would be 60-80%
4. I wager $____ that it would be 0-20%, and $____ that it would be 80-100%.
5. I wager $____ that it would be 20-40%, and $____ that it would be 40-60%.
6. I wager $____ that it would be 20-40%, and $____ that it would be 60-80%.
7. I wager $____ that it would be 20-40%, and $____ that it would be 80-100%.
8. I wager $____ that it would be 40-60%, and $____ that it would be 60-80%.
9. I wager $____ that it would be 40-60%, and $____ that it would be 80-100%.
10. I wager $____ that it would be 60-80%, and $____ that it would be 80-100%.
11. Rank each of the following according to likelihood of resulting habitat quality. A ranking of 1 is most likely, and a ranking of 5 is least likely.

    0-20% 4
    20-40% 2
    40-60% 1
    60-80% 3
    80-100% 5